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EFFECTS OF GROUP SELECTION WITH YELLOW BIRCH (BETULA ALLEGHANIENSIS) RETENTION ON THE UNDERSTORY AND SAPLING LAYER IN NORTHERN HARDWOOD FORESTS

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EFFECTS OF GROUP SELECTION WITH YELLOW BIRCH (*BETULA ALLEGHANIENSIS*) RETENTION ON THE UNDERSTORY AND SAPLING LAYER IN NORTHERN HARDWOOD FORESTS

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Preface

This thesis is submitted in partial fulfillment of a Master of Science in Forestry degree at Michigan Technological University. The data collection, analysis and writing were done under the supervision of Dr. Yvette Dickinson (School of Forest Resources and Environmental Science). The original work within this thesis is in preparation for submission for publication. Editorial comments were provided by Dr. Christopher Webster (School of Forest Resources and Environmental Science) and Dr. Tara Bal (School of Forest Resources and Environmental Science) during the writing process.

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Abstract

Gap partitioning theory predicts that changes in microenvironment conditions found within a forest opening promote diversity in forest ecosystems. Under this theory we would expect to see variations in tree and understory diversity throughout and surrounding a forest opening. In order to test this theory, we examined manmade openings with legacy-tree retention in a northern hardwood forest located in the Upper Peninsula of Michigan. This work is part of an ongoing study that was started in 2003 with the creation of 49 openings centered on a reserve dominant or co-dominant yellow birch (*Betula alleghaniensis* Britt.). The primary objective of this research was to assess if opening size, plot location and/or plot transect azimuth had an influence on the dependent variables that we measured (herbaceous-layer species, cover groups, and sapling). Twenty reference sites were also selected from the surrounding forest and centered on a dominant or co-dominant yellow birch. At each site, the following variables were measured; herbaceous-layer species percent cover, cover groups (tree seedling (< 50 cm), exposed soil, forest litter, exposed rock, woody shrubs, herbaceous plants, grass, sedge, rush, non-vascular plants, and woody debris), and sapling height (≥ 50 cm).

We found that both opening size and plot location were influential on our measured variables to varying degrees. We found no evidence that transect azimuth was a significant predictor of any of the dependent variables. Opening size was significant when analyzing species diversity and evenness. Plot location was also significant when measuring species diversity as well as richness. Correlations with cover groups varied

and some groups were not found to be associated with any of the opening measures (size, location, transect azimuth).

Mean tallest tree sapling height was not found to be significantly different among opening sizes, but sapling height was significantly shorter in the references sites than any of the harvested openings. We also found that saplings under the legacy tree were the tallest on average when compared to the opening and the surrounding forest. Maples were by far the most abundance sapling species with sugar maple (*Acer saccharum* Marsh.) being the most common. Continued monitoring of sapling survival and growth will be important to gain a better understanding of tree diversity in openings with legacy-tree retention and have a better understanding of the future forest composition.

1 Thesis Introduction

Silviculture in the Great Lake states has been developed over many years of application and experimentation. While much of the primary forests in the Upper Peninsula of Michigan were subject to high-grading and clear cutting between 1880s and 1920s (Whitney 1987), the secondary landscape has undergone a variety of management phases. At present in Michigan's northern hardwood forests a common approach to harvest is single-tree selection (Crow et al. 2002). This has been a favored method because selecting individual trees and creating small openings in the canopy mimics common natural disturbances, such as low-severity windthrow and single-tree death (Seymour et al. 2002). Over time, with application and studying, we have found that there are other methods that could be used when species diversity is a management objective. In this thesis, we continue to examine northern hardwoods with special attention the diversity and composition of the understory vascular plant community.

Single-tree selection has been a widely used management tool among foresters in northern hardwood ecosystems. This silvicultural technique involves selecting individual mature trees for removal throughout the stand in a uniform fashion (Nyland 2016). Single-tree selection has been shown to have many benefits for forest management such as small-scale diversity, a continuous supply of timber and minimal disturbance compared to other harvest methods (Arbogast 1957, Crow et al. 2002). Despite the benefits of single-tree selection, some researchers believe this method has been over applied in some regions of the northern hardwood landscape, leading to uniformity across the forested landscape scale (O'Hara 2001, Neuendorff et al. 2007). A species

composition shift from a mixture of shade intolerant, mid-tolerant and tolerant species to predominately shade-tolerant species such as sugar maple *(Acer Saccharum* Marshall) and red maple (*Acer rubrum* L.) has been recorded (Nyland 2003).

Researchers have questioned how a range of tree species from shade tolerant to intolerant have existed in the same area. The gap dynamic theory has been posed as an explanation for why a high diversity of species with different shade tolerances can exist together (Denslow 1987, Yamamoto 1992). This theory was first observed by Cooper (1913) and was expanded on by Watt (1947). The theory states that species that would not be able to regenerate under a closed canopy survive in the forest matrix because they are able to establish and grow in openings that are created in the canopy by the death of one or more trees (Denslow 1987). These openings, or gaps provide different microclimate conditions than are found in the surrounding forest. These microclimate conditions can be changes in the amount of light that reach the forest floor, the soil and air temperature, and the amount of moisture available within the opening (Ritter et al. 2005, Gendreau-Berthiaume et al. 2009). Because of these differences shade intolerant and mid-tolerant species can become established in these spaces.

To address the concerns of declining species diversity, a long-term study investigating the role of gap dynamics in species diversity was established in the Ford research forest, owned by Michigan Technological University. This study studied the effects of group openings on species diversity. With the help of the school's forester a location was chosen based on the management history and the abundance of dominant and co-dominant yellow birch (*Betula alleghaniensis* Britt.) that could be selected as legacy trees

(Shields et al. 2007, Poznanovic 2013). The forest is dominated by sugar maple and red maple and has a component of eastern hemlock (*Tsuga canadensis* (L.) Carr.) and yellow birch. Forty-nine openings were harvested with a dominant or co-dominant yellow birch retained in the center of each opening. The yellow birch legacy-tree was retained to be used as a seed source for the next generation of yellow birch regeneration. Theses group openings varied in size but were categorized of three size classes; small (267 m^2), medium (642 m^2) and large (1192 m^2). Twenty reference sites were also established with a dominant or co-dominant yellow birch marking the center of the site. These reference sites were located in in the surrounding forest that had been managed with single-tree selection (Schwartz 2004). This study was designed to test if novel harvest techniques can bolster mid-tolerant tree species recruitment. Gap dynamics has been studies throughout the world (Yamamoto 2000, McCarthy 2001), but the caveat of having a seed tree retained in the gap provides a unique system to study.

Now that this study has been established for 13 years we would like to re-evaluate the condition of the understory in these openings. The current investigation includes two parts. The first part is looking at the herbaceous layer's response to the harvested openings (Chapter 2). The herbaceous community can comprise the majority of vascular plant diversity in a forest (Whigham 2004, Falk et al. 2008). We also compared differences between harvested and unharvested locations. The second objective of this work was to examine sapling height (Chapter 3). Our hypothesis for this part of the experiment was that sapling height will be different depending on the location of the sapling within the harvested openings and reference sites. We hypothesized the tallest

sapling would be located in the north and east parts of the opening. This is important when considering the implication of gap closure and the future composition of the forest. We looked specifically at the species composition of the regeneration that was present at the time of the study.

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2 Effects of group selection with legacy-tree retention on the herbaceous layer in northern hardwoods

2.1 Introduction[1]

Gap partitioning theory hypothesizes that small-scale disturbances promote diversity in the forest by creating diverse microenvironments under the opening of the forest canopy and in the surrounding forest (Ricklefs, 1977). Under this theory, different species would occupy different niches along the gradient of environments from the most open part of the gap into the closed canopy forest (Runkle, 1982; Denslow et al., 1990; Busing et al., 1997). This theory has been studied around the world with large variation in results and conclusions with some studies finding evidence supporting this theory (Yamamoto, 2000; Scheller et al., 2002) and others finding no evidence to support it (Kern et al., 2006). In northern hardwood forests specifically, studies investigating how these openings may influence herbaceous species have had mixed results (Metzger et al., 1981, 1984; Shields & Webster, 2007; Campione et al., 2012).

The creation of an opening can change the amount of light, nutrient availability, as well as the soil moisture content of a small area (Coates et al., 1997; Brokaw et al., 2000). Opening size has been considered a major factor influencing the changes in the microenvironment, with larger openings having more exposure to sunlight than smaller ones (Whitmore, 1989; Denslow et al., 1990). While these changes in environmental

[1] The material contained in this chapter is in preparation for submission to Forest Ecology and Management, by M.A. Petras O'Neil, Y.L. Dickinson, C.R Webster, and T.L. Bal

resources may not last once the forest becomes re-established, the differences in short-term resource availability may have an impact on herbaceous species establishment and persistence.

Herbaceous species are an integral part of a forest ecosystem. In woodland communities herbaceous plants account for the majority of vascular species and the highest species richness (Whigham, 2004; Campione et al., 2012). Herbaceous plants provide food and habitat for a variety of mammals, birds and other organisms living in the forest (Martin et al., 1961). Logging has been found to have a significant impact on the herbaceous community, both temporary and long-term. (Alverson et al., 1988; Horsley et al., 2003). Therefore, it is important to monitor the effects of land-use and management on these communities.

Herbaceous plants respond more quickly than trees species to changes in the environment due to their faster growth and comparatively short life span. While herbaceous communities can be sensitive to forest disturbances both natural and anthropogenic and land-use (Burton et al., 2011), measuring differences in herbaceous communities can also be done on a shorter time scale than measuring the change in the tree species composition. Herbaceous plants may be able to provide information about how different harvesting systems change plant communities (Grace, 1999).

In this study, we investigated the effects of opening creation with legacy tree-retention on the herbaceous community over a thirteen-year time period at the Ford Research Forest located in the Upper Peninsula of Michigan. We examined the herbaceous communities

within and surrounding the openings to see how these communities differed. Specifically, the objective of this study was to test if the herbaceous community differed under the legacy tree, harvested portions of the opening, and the surrounding forest matrix. We also tested to see if azimuth from the legacy tree had an impact on the herbaceous community. We hypothesized that we would find differences in species composition in different areas of the opening due to the differences in available resources.

2.2 Methods

2.2.1 Study area

This study was located at the Ford Center Research Forest, Baraga County, Michigan approximately 4 km south of Alberta, MI (Section 30, T49N, R33W, 46º 37' N, 88º 29' W). The total study area was located in a northern hardwood stand which was approximately 235 hectares. Champion cobbly silt loams were the dominate soil types across the study area, with small inclusions of Net silt loams, Alstad silt loams, and Witbeck mucks (Berndt, 1988). The average elevation of the site was 430 m (Gesch et al., 2002). Annual average temperature ranged from -9.8 Cº in the winter to 17.4 Cº in the summer (NOAA, 2017). The terrain varied from nearly level to slightly hilly (Berndt, 1988).

The overstory of the study site was dominated by sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), and yellow birch (*Betula alleghaniensis* Britt.). Other minor tree species include, but are not limited

to: black cherry (*Prunus serotiona* Ehrh.), balsam fir (*Abies balsamea* (L.) Mill), ironwood (*Ostrya virginiana* (P. Mill.) K. Kock), American elm (*Ulmus Americana* L.), eastern white pine (*Pinus strobus L.*) and white spruce (*Picea glauca* (Moench) Voss).

2.2.2 Experimental Design

This study builds on a long-term investigation of group-selection with legacy-tree retention (Shields & Webster, 2007; Shields, Webster, & Glime, 2007; Shields, Webster, & Nagel, 2007; Klingsporn et al., 2012; Poznanovic, 2013; Poznanovic et al., 2013). In the winter of 2003/04, 49 openings were created. Each opening edge was at least 60 meters away from the next to reduce interactions. Within each opening all trees larger than 10 cm DBH (diameter at breast height) were cut. Opening size was determined based on a ratio of the mean canopy height of dominant and codominant trees (22 m). The ratios used were 0.5 (n = 16), 1 (n = 17), and 1.5 (n = 16) for small, medium and large opening, respectively. Resultant opening sizes were 267 ± 15 m^2, 642 ± 21 m^2, and 1192 ± 39 m^2 (mean ± 1 SE) for small, medium and large openings, respectively. Each opening was centered on a yellow birch, which was left as a residual legacy during harvest. In addition, twenty-four reference sites, with no harvested openings were also selected for comparison. The reference sites were also centered on a dominant or codominant yellow birch. The reference sites were in a management unit that had been managed with single-tree selection on an approximate 12-15 year rotation and a stocking criteria with a residual basal area of 16.1 m^2/ha, a maximum diameter of 50.8 – 55.9 cm and a q-ratio of 1.3 (5 cm classes) (Schwartz, 2004).

2.2.3 Data collection

The abundance and composition of the understory communities was measured in the summers of 2005, and 2012 (Shields & Webster, 2007; Klingsporn et al., 2012). Within in each opening and all reference sites, plots were established along the cardinal and subcardinal axes radiating out from the legacy tree. The plots consisted of a 1 m x 1 m square quadrat. Four plots were placed between the trunk of the yellow birch legacy-tree and the edge of its crown in the cardinal directions. Eight plots were established at random locations between the edge of the yellow birch crown and the edge of the crown of the surrounding forest in cardinal and subcardinal directions

At each 1 m x 1 m plot, percent cover of all understory plants was determined and recorded by species. Also, percent cover of the following cover groups was determined: tree seedlings, woody shrubs, herbaceous plants, grasses, sedges, non-vascular plants, rushes, exposed soil, forest litter, exposed rock and woody debris. Given the timing of the survey (July-August), spring ephemeral species were not included.

During the summer of 2016 (July-August), we resampled a subset of the plots from 44 openings and 19 reference sites (small n=16, medium n=17, and large n=16). We limited sampling to plots along the 4 cardinal axes, and added an additional plot on each axis under the forest canopy at a random distance between 0 and 30 m from the opening edge (Figure 2.1 and Figure 2.2).

2.2.4 Statistical analysis

2.2.4.1 Species Diversity

To test our hypotheses that herbaceous plant communities would have higher diversity within the openings, we calculated Shannon-Wiener (H') diversity index, species richness (S), and species Pielou's evenness (J) for all plots measured in 2016 (Jari et al., 2017). Analysis of Variance (ANOVA) followed by pairwise comparisons with Holm's adjustment was used to test for differences between openings and closed canopy conditions (Zar, 1999; Crawley, 2013). The diversity measures were compared among the four opening sizes (small [n=13], medium [n=15], large [n=16], and reference [n=19]), and locations within the openings. Location was described by two factors; transect azimuth (North, East, South and West), and position along transect (under the legacy tree canopy, in the opening, and under the canopy of the surrounding forest). We also included all possible interactions terms among the factors. Normal probability plots and standardized residuals were used to test the assumptions of normality and constant variance of errors.

To examine how herbaceous plant communities differed among opening size and location among the 2016 percent cover data we used nonmetric multidimensional scaling (NMS) ordination in PC-ORD version 6 (McCune and Grace, 2002). The auto pilot mode was used with Sorensen (Bray-Curtis) distance measure and a random starting configuration. We selected the no penalty tie handling method, which does not penalize ties with unequal ordination distance. The final ordination was performed using 50 runs with real data and 50 runs with randomized data with a maximum of 200 iterations. Based on the

results of a Monte Carlo test a two-axis solution was selected. For this analysis, we removed species of low occurrence in order to reduce the noise in the ordination. Low occurrence was defined as any species that occurred fewer than 3 times across all plots.

2.2.4.2 Cover groups

We tested percent cover of the cover groups between opening sizes and locations in 2016. The normality assumption was not met so data were then transformed using a Box-Cox transformation (Venables, 2002). An analysis of variance test was done on each of the cover groups, comparing opening sizes and locations. We also included the possible interaction of each of the factors. Follow up pairwise comparisons with Holm's adjustment were done for all comparisons that were statistically significant results ($P \leq 0.05$) (R core team, 2015).

Nonmetric multidimensional scaling was used to study how percent cover of all cover group composition was influenced by opening size and location in the 2016 data (PC-ORD version 6). Sorensen (Bray-Curtis) distance measure with a random starting point was used with the auto pilot mode with the no penalty tie handling method. A three-axis solution was selected bases on the results of a Monte Carlo test. The final ordination was performed using 50 runs with real data and 50 runs with randomized data.

2.2.4.3 Change in species cover between 2005 and 2016

In order investigate changes in the individual species composition within the opening size over time, we compared the species cover data collected in the summer of 2005 to the data we collected in the summer of 2016. We used nonmetric multidimensional scaling

ordination to examine species composition between years. The ordination was done using PC-ORD version 6 on autopilot with the Sorensen (Bray-Curtis) distance measure and the no penalty tie handling method. The ordination was run 250 times with real data and 250 times with randomized data. The final ordination resulted in a 2-dimensional solution.

2.3 Results

2.3.1 Species Diversity

There was a gradient in Shannon's diversity index among the opening sizes, with large openings having the highest Shannon's diversity index (0.47 ± 0.033, mean ± 1 SE) and medium openings the lowest (0.31 ± 0.029; $P < 0.001$) (Figure 2.3). Small openings and reference sites had intermediate Shannon's diversity indices (small = 0.43 ± 0.032, reference = 0.35 ± 0.028), and were not statistically different from each other ($P = 0.216$). In addition, plot position along transect was statistically significant ($P = 0.016$; Figure 2.4). Plots in the opening had a higher Shannon's diversity (0.43 ± 0.025) than plots under the legacy-tree crown (0.33 ± 0.026, $P = 0.014$). The Shannon's diversity of the forest plots (0.34 ± 0.026) was not statistically different from those under the legacy tree ($P = 0.164$) and in the opening ($P = 0.276$). Shannon's diversity did not significantly differ among the transect azimuths ($P = 0.328$).

In contrast to Shannon's diversity, species richness differed among all plot positions (Figure 2.5). Richness was highest in plots positioned in the opening (2.39 ± 0.081) and lowest under the legacy-tree crown (1.72 ± 0.081). Specifically, richness was

significantly higher in the openings than the forest (P = 0.014) and under the legacy tree (P = <0.001). The forest plots had higher richness (2.06 ± 0.083) than those under the legacy tree (P = 0.014). The ANOVA comparing Shannon's diversity index across the range of opening sizes detected statistically significant differences (P = 0.018). However, pairwise comparisons using the Holm's correction did not find statistically significant differences between any opening sizes (all P > 0.1) We found no statistically significant differences among transect azimuths (P = 0.27).

Similar to Shannon's diversity, species evenness differed among opening sizes. Species evenness was significantly higher in the large openings (0.40 ± 0.028) than the medium openings (0.37 ± 0.031; P = 0.002; Figure 2.6). The small openings' evenness (0.44 ± 0.032) was also higher than the medium openings (P = 0.009). Reference sites species evenness (0.36 ± 0.26) was lower than the large openings (P = 0.036). We found no significant differences amongst transect azimuths (P = 0.598) or plot positions (P = 0.079).

The herbaceous plant community NMS ordination had a two-dimensional solution with a final stress of 18.9 (Figure 2.7). According to Kruskal's rule of thumb this stress level is considered fair to poor (McCune and Grace, 2002). A total of 65% of the variation in the herbaceous plant community composition was explained by the ordination with axis 1 accounting for most of the variation ($r^2 = 0.416$) followed by axis 2 ($r^2 = 0.230$). Neither axes were meaningfully correlated with opening size (Axis 1 r = -0.11 and P < 0.001, Axis 2 r = 0.020 and P < 0.001) or transect azimuth (Axis 1 r = -0.020 and P < 0.001, Axis 2 r = 0.080 and P = 0.006).

2.3.2 Cover Groups

Large openings had the highest average percent cover of shrubs (11% ± 2%) and reference sites had the lowest (1% ± 0.5%; $P < 0.001$, Figure 2.8). Furthermore, reference sites had lower shrub cover than small ($P = 0.004$), medium ($P < 0.001$) and large openings ($P < 0.001$); however, the small, medium, and large openings were not significantly different from each other (All $P > 0.05$). Plot position was also a factor associated with shrub cover. Plots in the openings had an average of 12% ± 2% cover while the under the legacy tree and in the forest had 4% ± 1% and 1% ± 0.6%, respectively. Plots positioned in the openings had a higher shrub cover than plots under the legacy tree ($P <0.001$) and plots in the forest ($P < 0.001$; Figure 2.9). We found no statistically significant differences among transect azimuths ($P = 0.918$).

Herbaceous percent cover was lower under the legacy-tree crown than the opening and forest, but did not differ between the forest and opening plot positions (Figure 2.10). Specifically, plots under the legacy tree had an average of 10% less herbaceous cover than the other two locations (opening, $P < 0.001$; forest, $P < 0.001$). No significant differences were found amongst opening sizes ($P = 0.114$) or transect azimuths ($P = 0.927$).

Seedling percent cover differed among opening sizes (Figure 2.11). Large opening had an average of 4% higher seedling cover than medium openings ($P = 0.007$), but there was no difference with small openings ($P = 0.694$) or reference sites ($P = 0.190$). We found no differences in seedling cover amongst transect azimuths ($P = 0.079$) or plot positions ($P = 0.465$).

Exposed rock percent cover significantly differed only between the small and medium openings ($P = 0.004$), but both sizes had an average of less than 1% cover. Percent cover of course woody debris was higher under the legacy-tree crown than it was in the surrounding forest ($P = 0.021$), the difference was 1%. No statistically significant differences were found among opening sizes or plot position or transect azimuth for the forest litter, bare soil, sedges, grasses, or rushes cover groups (All $P > 0.09$).

The NMS ordination for cover groups resulted in a 3-dimensional solution with a final stress of 13.09. Kruskal's rule of thumb (McCune and Grace, 2002) suggests that this level of stress is considered fair, and can be used for inference. The ordination explained 93% of the variation in the cover group composition, with axis 1 explaining the most variation ($r^2 = 0.406$), then axis 2 ($r^2 = 0.304$) and axis 3 explaining the least variation ($r^2 = 0.221$). Since axis 1 and 2 explained the majority of the variation of cover group composition they are presented (Figure 2.12). The axes were not meaningfully correlated with opening size (Axis 1 $r = 0.099$ and $P = 0.010$, Axis 2 $r = -0.002$ and $P < 0.001$) or transect azimuth (Axis 1 $r = 0.002$ and $P < 0.001$, Axis 2 $r = -0.007$ and $P < 0.001$).

2.3.3 Change in species percent cover between 2005 and 2016

The NMS ordination of herbaceous species between years showed that while there was some separation of groups by year and gap size, these differences were not statistically significant (Figure 2.13). The ordination resulted in a 2-dimensional ordination with a stress of 14.6. Seventy percent of the variation was explained, with axis 1 explaining the most variation ($r^2 = 0.476$) and axis 2 explaining the rest of the variation ($r^2 = 0.227$). The

two axes were not significantly correlated with opening size (Axis 1 r = 0.149 and P = 0.022, Axis 2 r = -0.003 and P < 0.001), transect azimuth (Axis 1 r = -0.009 and P < 0.001, Axis 2 r = 0.014 and P < 0.001) or plot position (Axis 1 r = -0.138 and P = 0.019, Axis 2 r = -0.040 and P = 0.002).

2.4 Discussion

Our results indicate both opening size and position along transect to be two important factors in our study while assessing plant communities. Using a combination of ANOVAs and NMS ordinations we were able to test our hypothesis that plant communities and cover groups would differ within and around the opening. In this study, we measured three different opening characteristics; opening size, transect azimuth, and position along transect to test if the openings were expressing any characteristics that would be expected under the gap portioning theory.

We found trends among openings size and plot position along transects in Shannon's diversity index, but these trends were not as simple as we had hypothesized. The large openings had the highest Shannon's diversity index value, which was what we expected to find, but the other opening sizes did not have a clear trend. This outcome showcases the complexity of these systems. While our results indicated that opening size maybe a factor in determining species diversity, we were only able to show this for the largest openings. These results are similar to the finding of Shields and Webster (2007) who were unable to find significant differences among the opening sizes. Based on Shannon's diversity we did not find evidence of gap partitioning theory.

Plot position was also influential on Shannon's diversity. The dissimilarity between the Shannon's diversity index of plots under the legacy tree and plots in the opening leads us to conclude that the presence of a legacy tree is influencing the environment directly under the canopy of that tree. No noteworthy differences were found in the Shannon's diversity of plots in the surrounding forest and plots directly under the legacy tree which is further evidence that the legacy tree is influencing the herbaceous communities directly under its crown, and the environmental condition could be similar to those found in the surrounding forest.

A similar trend was observed with species richness. The highest richness was also found in the opening and richness was lower under the legacy-tree and in the surrounding forest. This is similar to the findings of Scheller and Mladenoff (2002) where they observed the higher species richness in managed stands while we observed higher species richness in the harvested portions of the openings. In our study we did not measure light availability or soil moisture, but other studies have found a difference in these resources between openings and under canopy (Gálhidy et al., 2006; Gendreau-Berthiaume et al., 2009).

We also found when testing species evenness that opening size was a principal factor. Opening size had been found to be important in other studies as well (Denslow et al., 1990). Again, large opening had the highest species evenness. This could be due to there being more light available to plants growing in these locations. Similar results have been found in other work that shows that resources are variable throughout the space of an opening (Gray et al., 1996; Gendreau-Berthiaume et al., 2009).

In our study, we found no difference in shrub cover among any of the opening sizes which did not support our hypothesis that opening size would affect percent cover of shrubs, but the reference sites did differ from all opening sizes. Percent cover of shrubs also differed among plot location which what we expected to find. The most common shrub species found in this study was raspberry. Several studies have shown that raspberry cover may inhibit tree regeneration, but it is not as well understood how raspberry cover effects herbaceous plant communities (Donoso et al., 2006). From the results of our study opening size did not strongly influence shrub abundance because percent cover did not differ significantly between opening sizes.

The observed trends in percent cover of herbaceous community composition among opening plot positions along transects could be due to light availability. Light has been found to vary within openings (Gendreau-Berthiaume et al., 2009). The plots located in the opening would likely have the most available light reaching them after harvest and were found to have the highest percent cover of herbaceous species. Furthermore, the amount of direct light is known to effect herbaceous plant growth (Gálhidy et al., 2006). We found that herbaceous plant cover was influenced by the retention of the legacy tree in the center of the opening. This could be because the legacy tree changes light availability in the surrounding space. Plots that were under the legacy-tree canopy had lower herbaceous cover than both the plots in the forest and the plots in the gaps. No difference was found in herbaceous cover between the opening plots and the forest plots. The presence of the legacy-tree could be influencing the environment directly underneath its canopy by changing the resource availability.

Seedling percent cover was highest in the large openings but only marginally higher than the medium openings. The relatively small difference in percent cover could be due to the amount of time since harvest. Seedlings that were present as advanced regeneration at the time of harvest may have been recruited in to the sapling layer in the larger openings, but without pre-harvest data we are unable to conclude with certainty if this is the case (Poznanovic et al., 2013). We did not find data to support the partitioning of openings among seedlings at different locations of the openings.

We hypothesized that transect azimuth would be a predictor of herbaceous plant species and cover groups, but we did not find evidence to support this with our study. This could be due to the presence of the legacy tree in the center of the openings. Having a centrally located residual tree may limit the effect of transect azimuth on plant communities. The gradient of light along transect azimuths would be interrupted by the presence of dominant or codominant tree increasing shade in the openings, especially in smaller openings.

In conclusion, we are not able to find strong evidence that the understory communities of these opening were exhibiting characteristics that would be expected under the gap portioning partitioning? theory. This could be explained by the presence of the legacy-tree found in each opening, which would disrupt the pattern of light found in a gap not containing a central legacy-tree. While our hypothesis that difference species and cover groups would occupy difference locations within the opening was not supported, this research provides more information about the long-term effects of novel silviculture techniques, and the lasting effect opening creation with legacy-tree retention has on the

herbaceous plant community and cover groups. This work adds to an ongoing study of the impact of harvested-openings with legacy-tree retention in northern hardwood systems. Long term studies provide important insight into ongoing ecological processes. More work is needed to understand the specific environmental conditions of these gaps such as light, moisture and nutrient availability. Future monitoring of long term studies like this will lead to better understanding of northern hardwood forests.

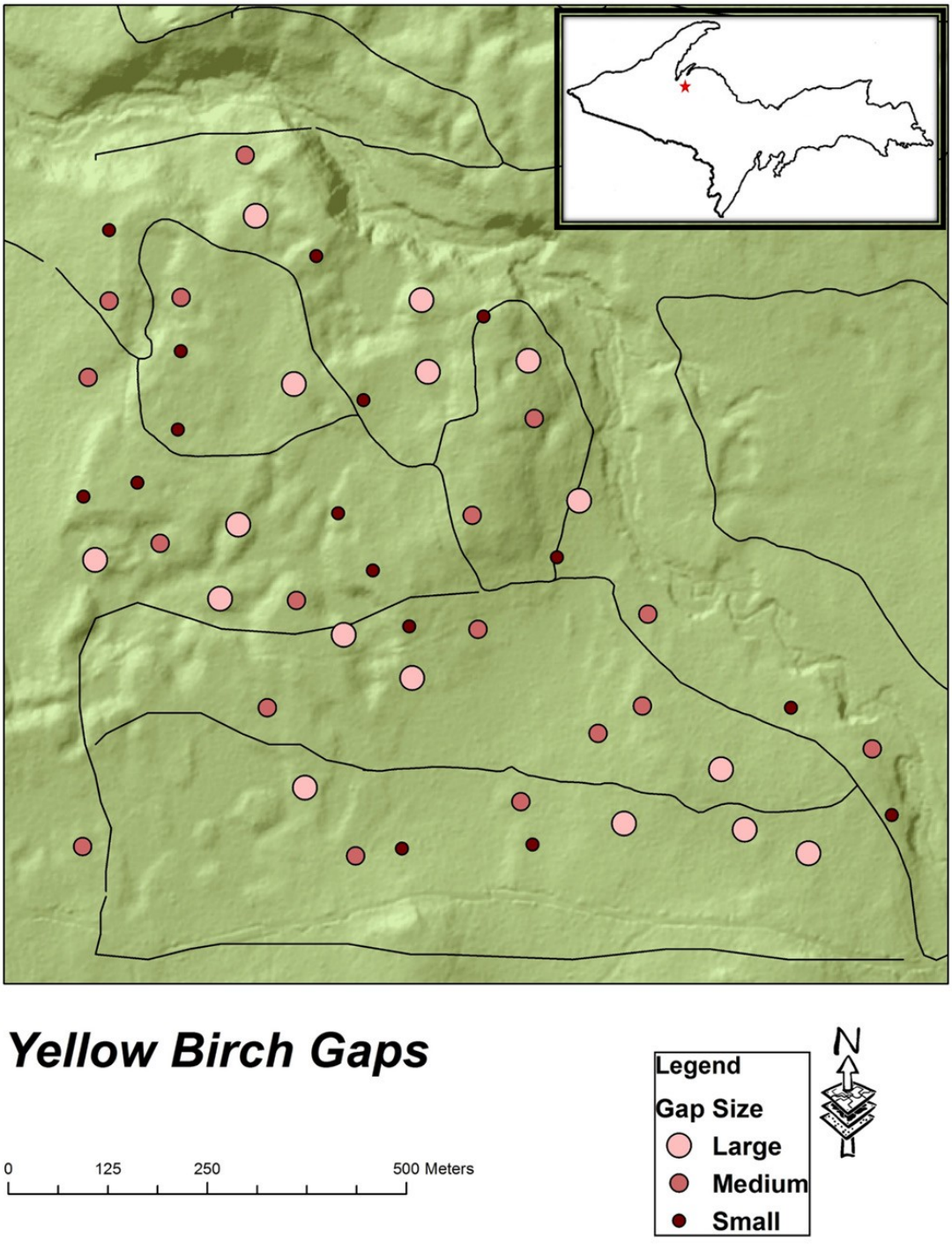

Figure 2. 1 Map showing location and size of canopy openings created at the Ford Center Research Forest in 2004. Locations of gaps are overlaid on a hill shading indicating the flat to rolling topography. Black lines indicate forest roads. Inset shows location of Ford Center Research Forest in Baraga County, in Upper Michigan.

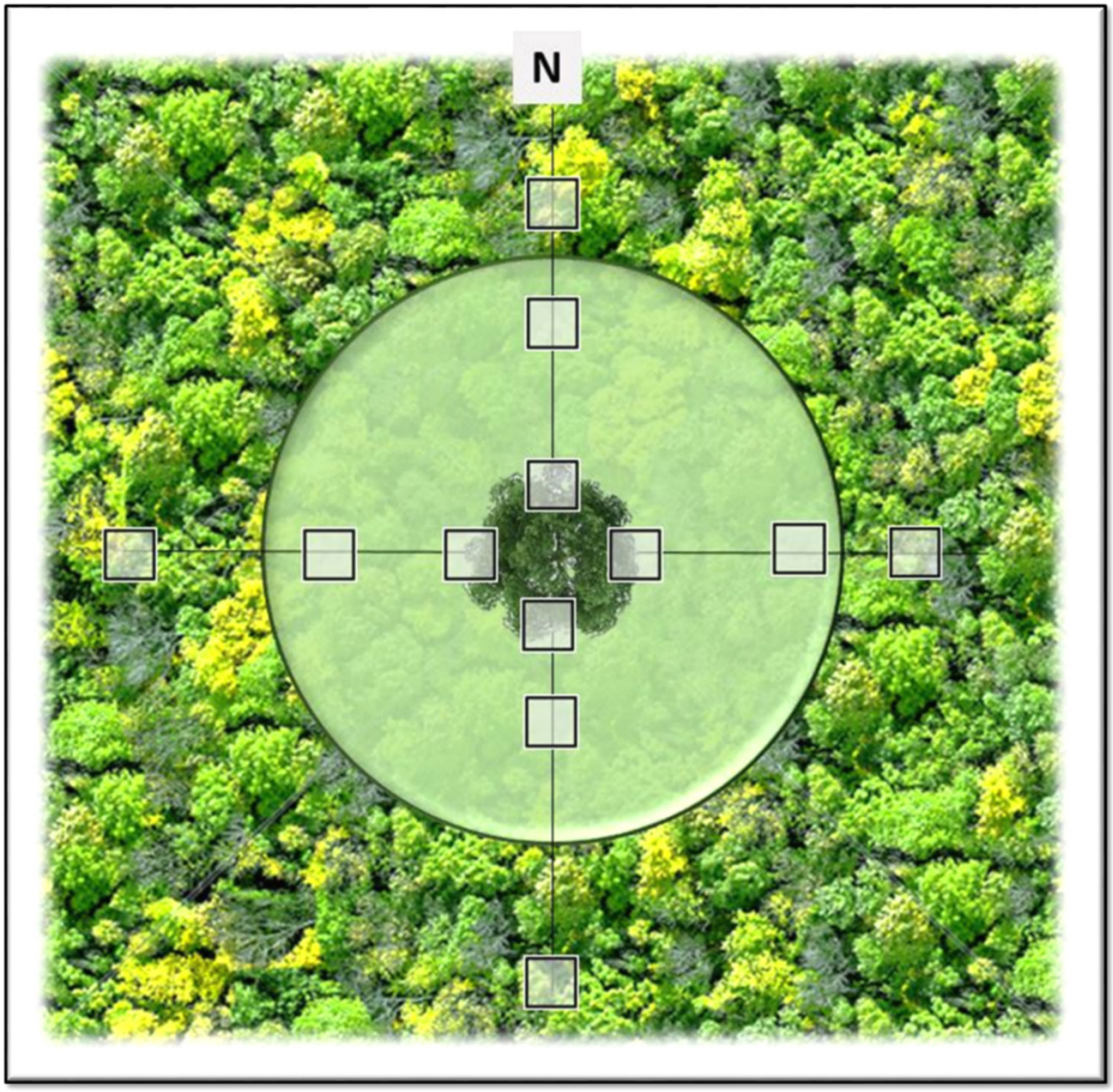

Figure 2. 2 Layout of plots within each canopy opening measured in 2016. Each opening was centered on a residual legacy tree, and the regeneration plots were located under the canopy of the legacy tree, in the opening, and in the forest along four cardinal transects

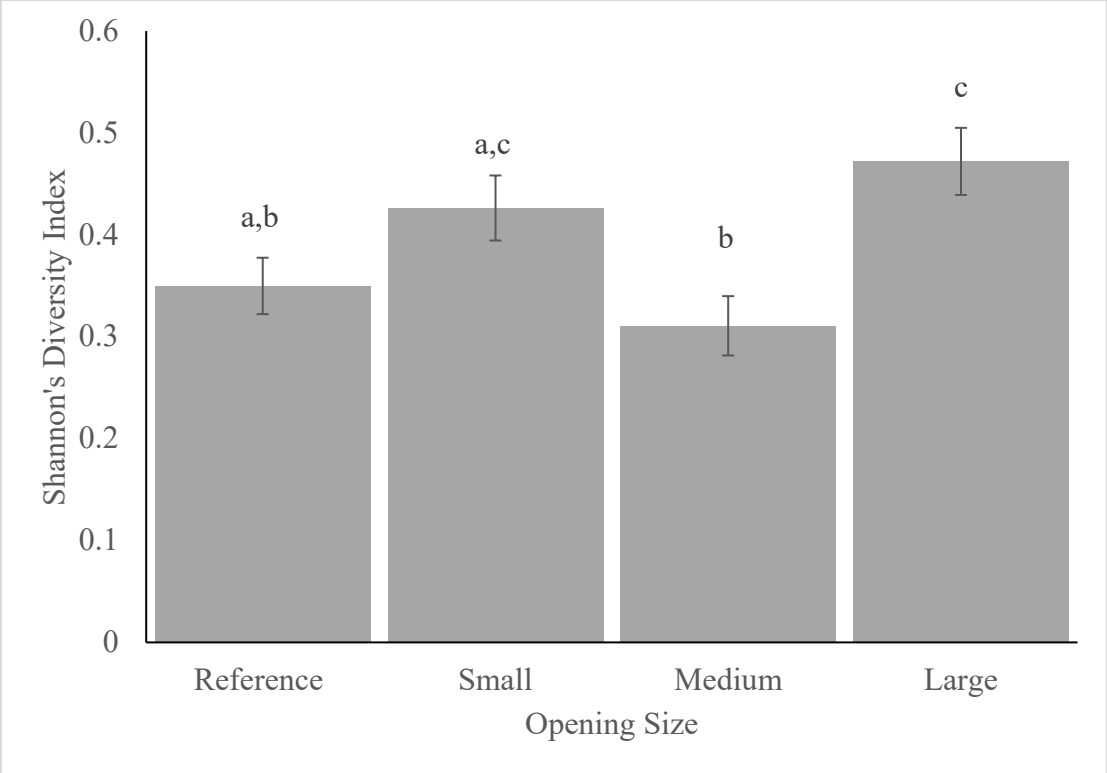

Figure 2. 3 Mean Shannon's diversity index of regeneration plots at reference sites, and in small, medium, and large openings. Error bars represent one standard error either side of the mean. Superscripts indicate statistically significant differences among the opening sizes.

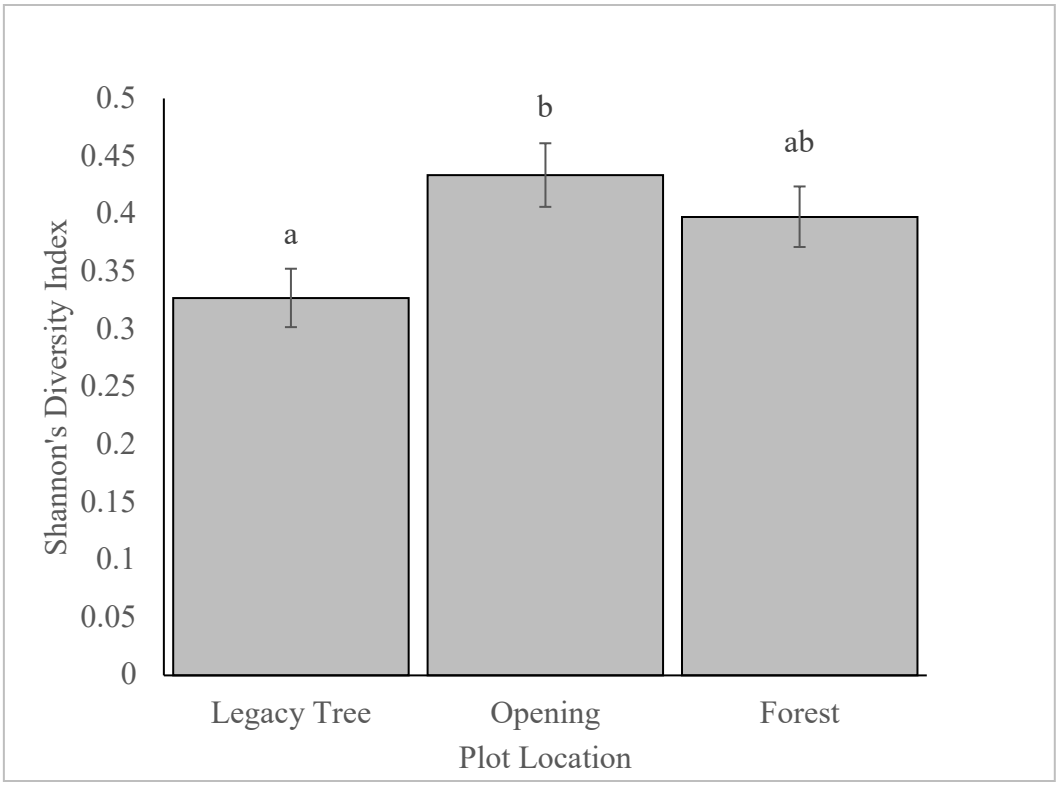

Figure 2. 4 Mean Shannon's diversity index of regeneration plots at plot locations (legacy Tree, Opening and Forest). Error bars represent one standard error either side of the mean. Superscripts indicate statistically significant differences among plot locations.

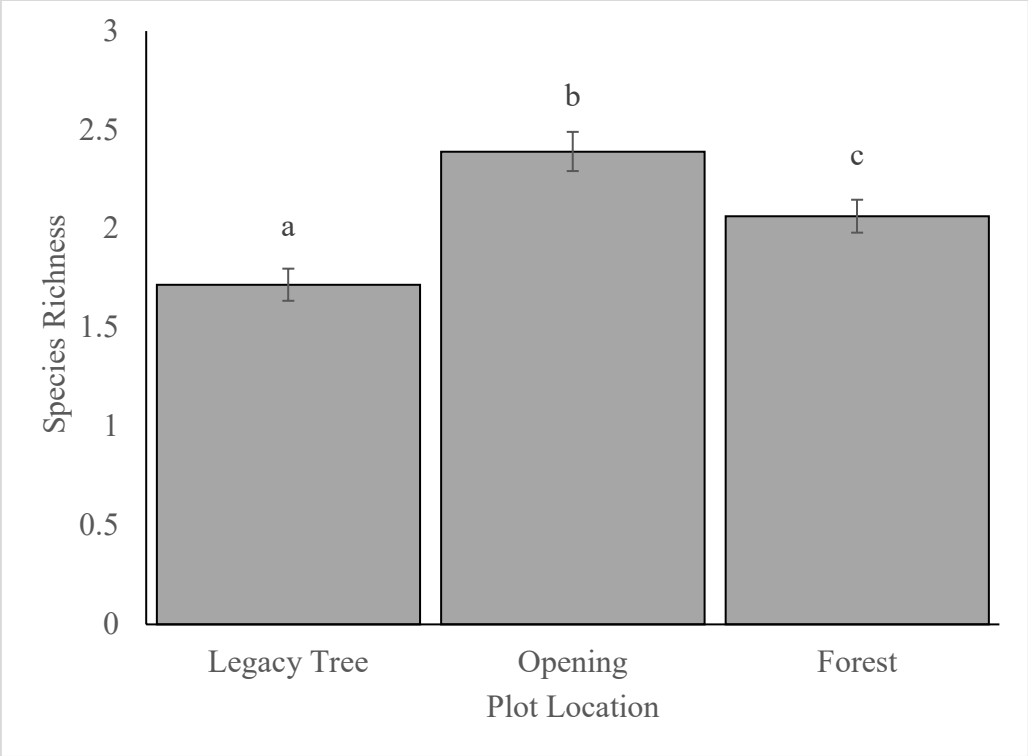

Figure 2. 5 Mean richness of regeneration plots at plot locations (legacy tree, opening and forest). Error bars represent one standard error either side of the mean. Superscripts indicate statistically significant differences among plot locations. Evenness

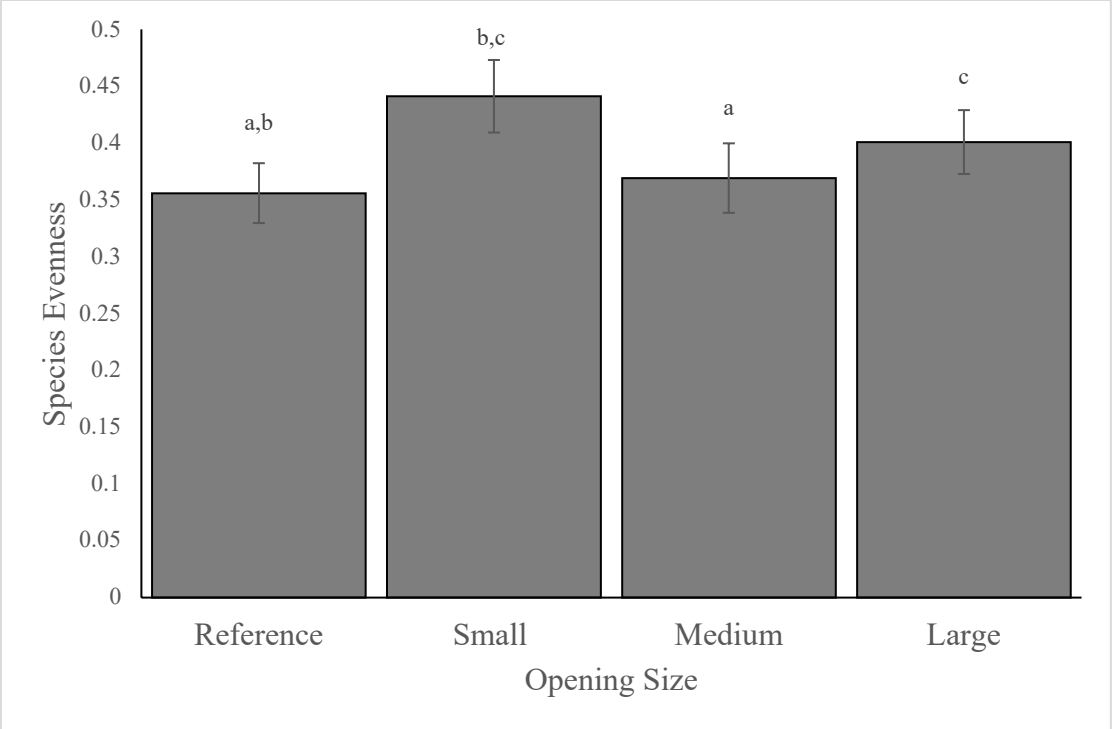

Figure 2. 6 Mean evenness of regeneration plots at reference sites, and in small, medium, and large openings. Error bars represent one standard error either side of the mean. Superscripts indicate statistically significant differences among opening sizes.

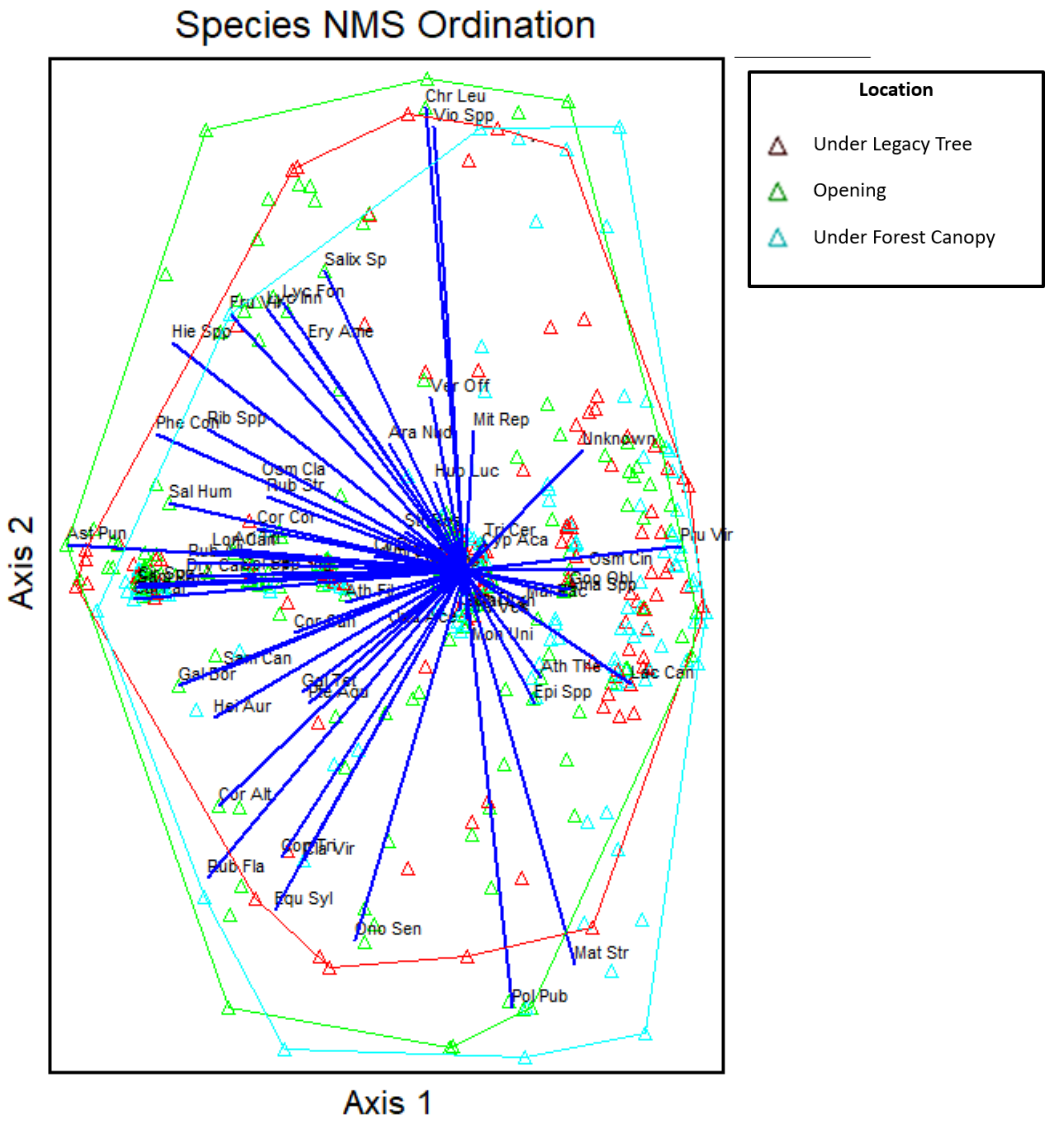

Figure 2. 7 Non-metric multidimensional scaling (NMS) ordination of individual understory species sampled at the Ford Center Research Forest in the summer of 2017. Axis 1 accounts for 42% of the variation in the data and axis 2 accounts for 23% of the variation in the data. Radiating lines are individual species vectors. Species abbreviations can be found in appendix 1.

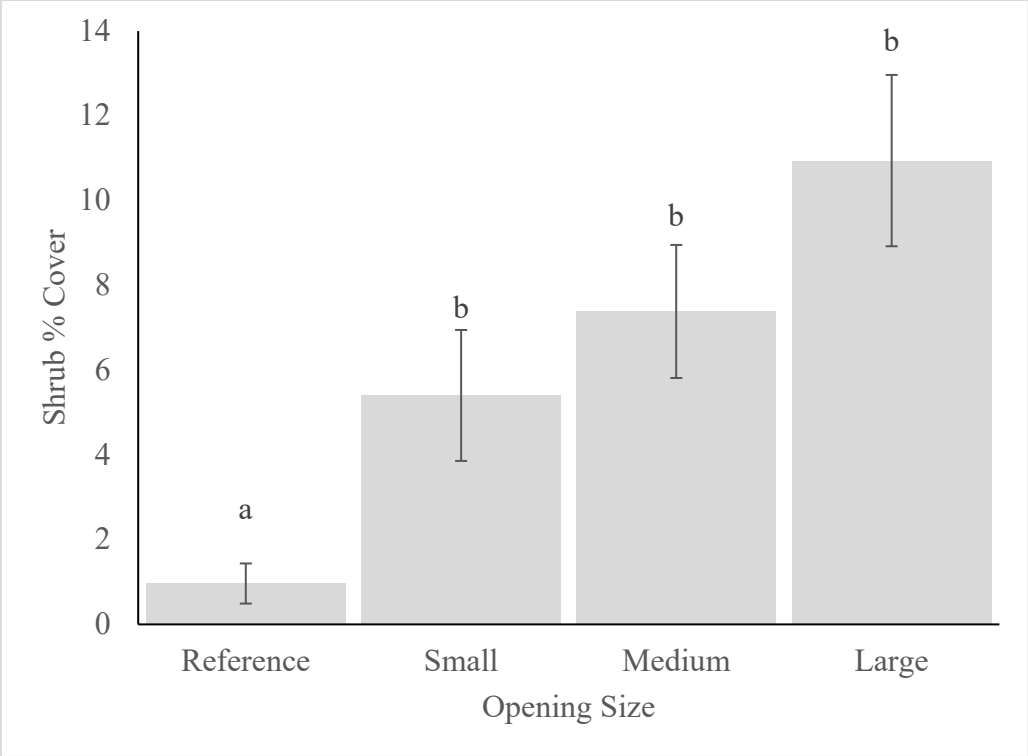

Figure 2. 8 Mean shrub percent cover of regeneration plots at reference sites, and in small, medium, and large openings. Error bars represent one standard error either side of the mean. Superscripts indicate statistically significant differences among opening sizes.

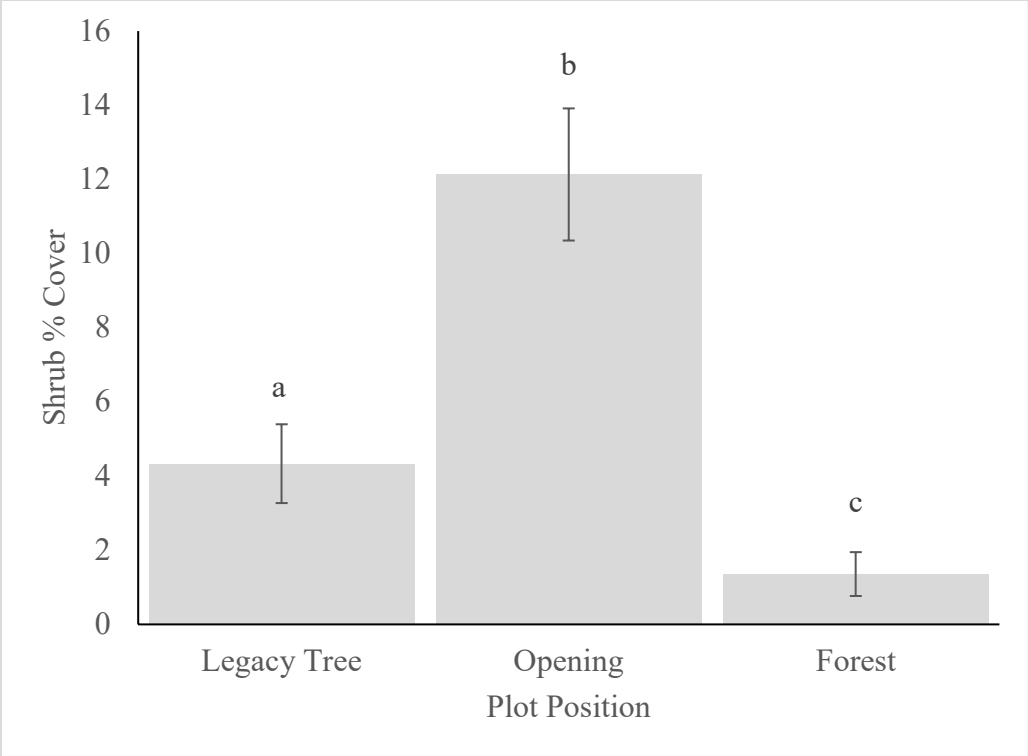

Figure 2. 9 Mean shrub percent cover of regeneration plots at plot locations (legacy tree, opening and forest). Error bars represent one standard error either side of the mean. Superscripts indicate statistically significant differences among plot locations.

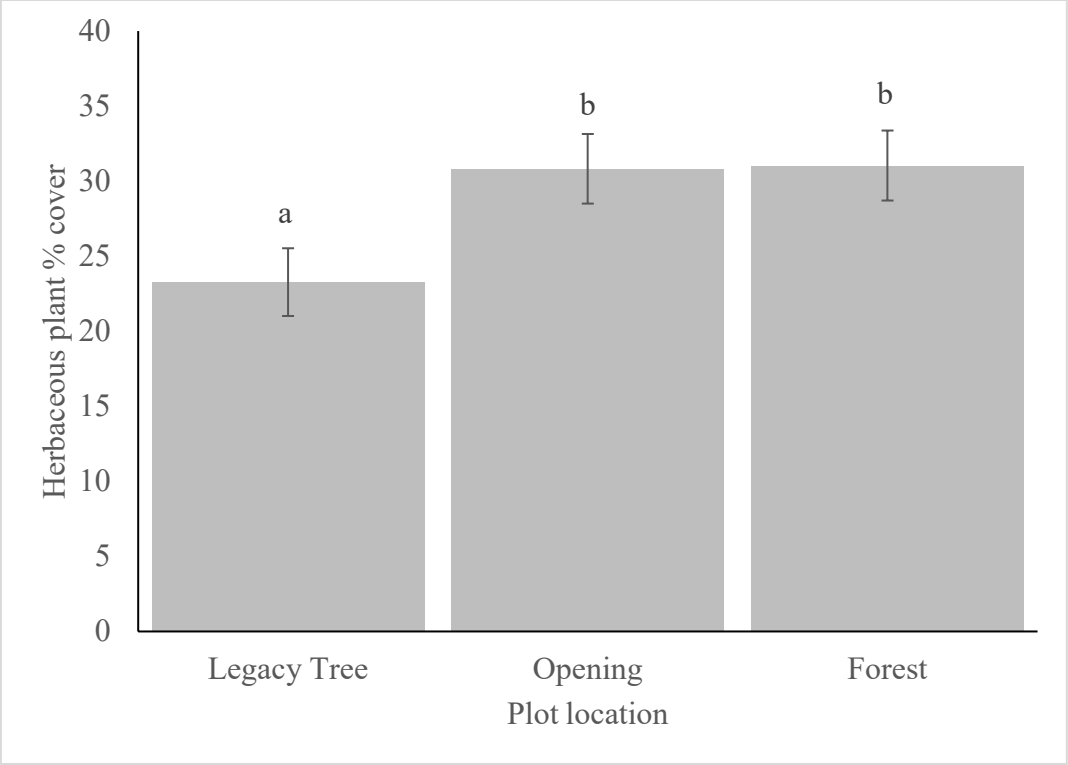

Figure 2. 10 Mean herbaceous percent cover of regeneration plots at plot locations (legacy tree, opening and forest). Error bars represent one standard error either side of the mean. Superscripts indicate statistically significant differences among plot locations.

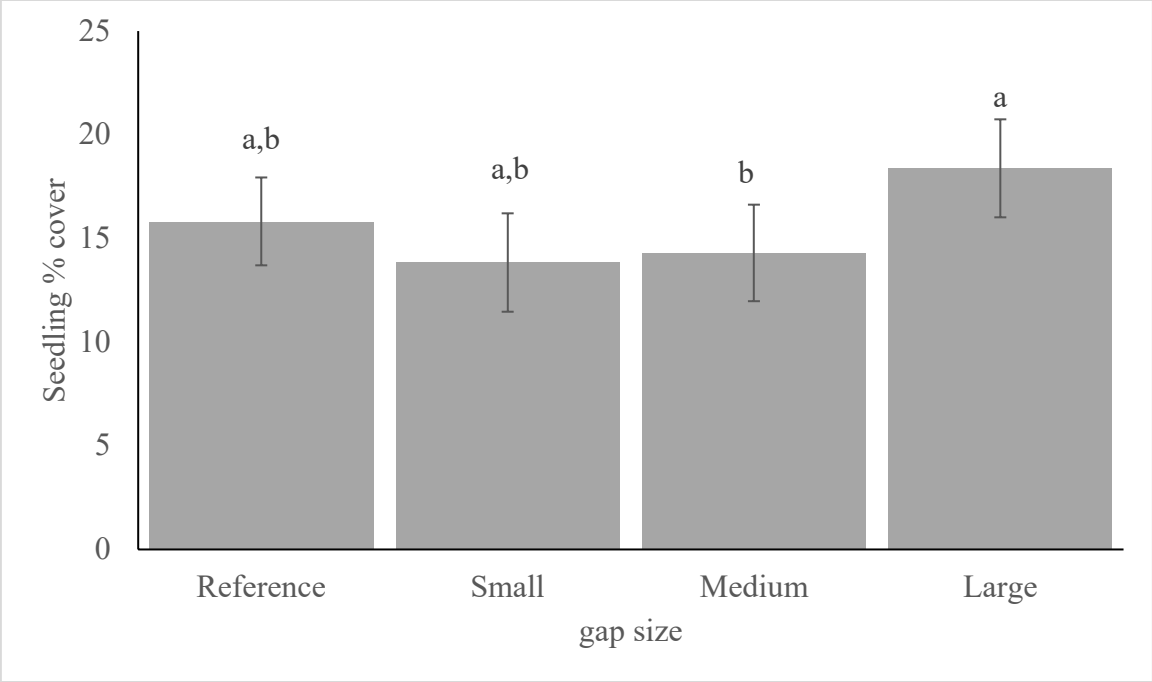

Figure 2. 11 Mean seedling percent cover of regeneration plots at reference sites, and in small, medium, and large openings. Error bars represent one standard error either side of the mean. Superscripts indicate statistically significant differences among opening sizes.

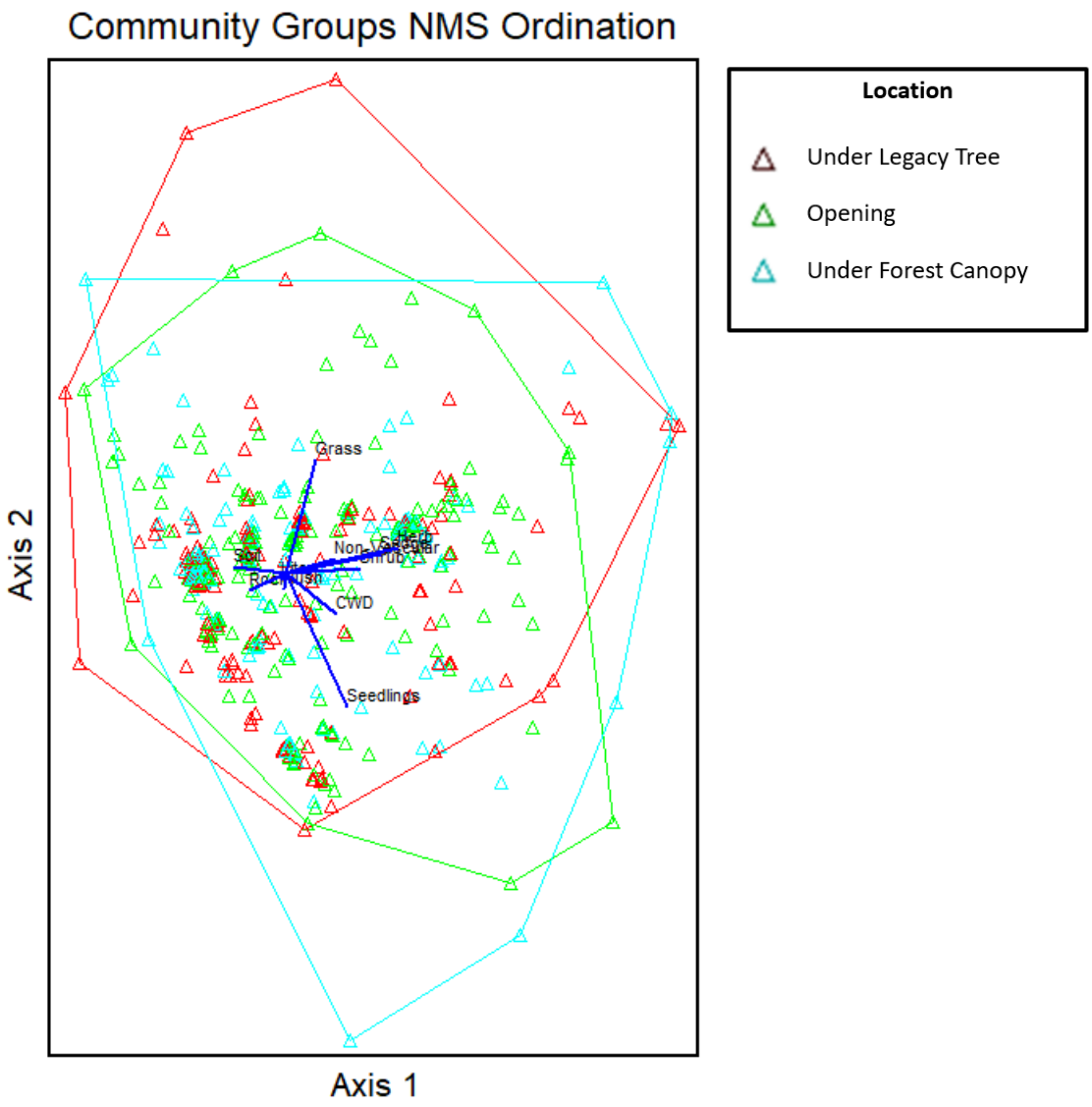

Figure 2. 12 Non-metric multidimensional scaling (NMS) ordination of cover groups sampled at the Ford Center Research Forest in the summer of 2017. Axis 1 accounts for 40% of the variation in the data and axis 2 accounts for 30% of the variation in the data.

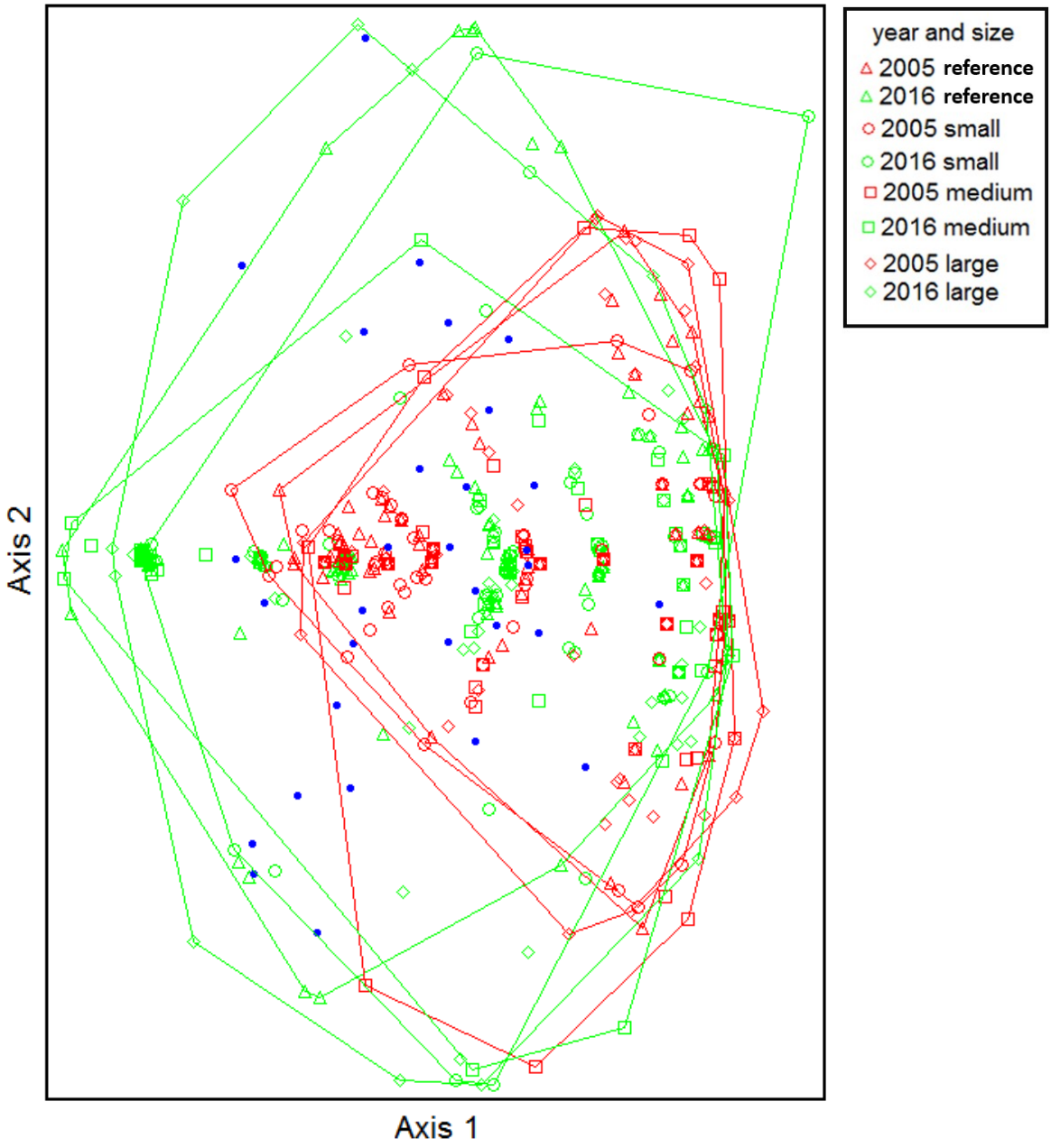

Figure 2. 13 Non-metric multidimensional scaling (NMS) ordination of openings by year. Year 2005 is represented in red and year 2016 if represented in green. Axis 1 accounts for 48% of the variation in the data and axis 2 accounts for 23% of the variation in the data. Blue circles represent individual species.

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3 Filling in the gaps: A look at sapling layer height in group selection openings

3.1 Introduction[2]

Gap dynamics is the process by which trees regenerate and recruit in openings created in the forest canopy (Brokaw et al. 2000, Yamamoto 2000). These canopy openings may occur naturally through the mortality of small groups of trees, or may be created by silviculturists as a forest management tool (Coates et al. 1997, Zhu et al. 2003). Whether gap formation occurs naturally or through forest management, the creation of an opening affects the environment within the newly created opening, and in the adjacent surrounding forest (Ritter et al. 2005). Generally, the temporary increase in light, water and nutrient availability in these can openings can lead to rapid growth rates (Canham 1988, Gendreau-Berthiaume et al. 2009). However, the availability of resources such as more light in the northern section of an opening, soil moisture changes depending on microsite conditions and plant competition have been found to vary within openings and the surrounding forest (Canham et al. 1990, Clinton et al. 1994, Gendreau-Berthiaume et al. 2009). In addition, species of tree seedlings and saplings vary in terms of their ability to capture and efficiently utilize resources, and therefore have differential responses to the variation in environmental conditions (Denslow et al. 1990).

[2] The material contained in this chapter is in preparation for submission to Forest Ecology and Management, by M.A. Petras O'Neil, Y.L. Dickinson, C.R Webster, and T.L. Bal

As trees regenerate, some trees may grow faster than others due to the variation in environmental conditions and the differential response of tree species. A small number of individuals will eventually dominate the space, capturing the available resources in an opening (known as “gap capture”). This gap capture is an important factor in the future composition of the forest (Whitmore 1989), with species that capture gaps tending to continue to dominate the composition of the forest for a period of time.

The study of gap dynamics in the northern hardwoods of the Lake States has seen renewed interest because the small openings typically created by single-tree selection (a common silvicultural system used in these forests) may lead to a dominance of shade-tolerant tree species (Leak et al. 1977, Brewer et al. 1978, Clinton et al. 1994, Crow et al. 2002, Previant 2015). As an alternative, forest managers have begun using group-selection with larger canopy openings to promote recruitment of shade-intolerance and mid-tolerant tree species including yellow birch (*Betula alleghaniensis* Britt.) (Leak 1999, Webster et al. 2005). However, the recruitment of shade-intolerant and mid-tolerant trees species has not been as successful in these larger opening as forest managers hoped (Houle 1998), and this poor recruitment may be due to poor seed dispersal into the openings. To address this problem, it has been proposed that forest managers should leave a legacy yellow birch in the openings to provide a seed source and maintain a yellow birch component in the stand (Shields et al. 2007, Shields et al. 2007, Shields et al. 2007, Klingsporn et al. 2012, Poznanovic 2013, Poznanovic et al. 2013). The crown of this residual legacy tree within the opening is likely to modify the

environment, and questions remain about the response of the sapling layer in these openings with a legacy tree.

The objective of this study was to examine differences in the regeneration and recruitment of trees among opening sizes and locations within man-made openings, with special attention to the dominant species (sugar maple, *Acer saccharum* Marsh.). We re-visited harvested openings with legacy-tree retention that had been established in the winter of 2003, and investigated sapling height as an indicator of regeneration success. We postulated that the tallest sapling 13 years after a harvest would be most likely to capture and dominate the available growing resources, and therefore occupy space in the forest canopy in the future. We hypothesized that sapling height would differ among opening sizes, plot locations and transect azimuths, with taller saplings in the larger openings due to greater availability of direct light. We also expected to find taller saplings in the northern half of the opening because we hypothesized that the northern part of the opening receives more light than other sections of the opening (Gendreau-Berthiaume et al. 2009).

3.2 Methods

3.2.1 Study area

The study area was located in the Ford Research Forest managed by Michigan Technological University in the western Upper Peninsula of Michigan. The study site was situated within a 235-hectort tract of northern hardwood forest, approximately 4.5 km from the village of Alberta, MI. The forest is dominated by sugar maple (*Acer*

saccharum Marsh.) and red maple (*Acer rubrum* L.) as well as yellow birch, and eastern hemlock (*Tsuga canadensis* (L.) Carr.) to a lesser extent. American basswood (*Tilia Americana* L.), ironwood (*Ostrya virginiana* (P. Mill.) K. Kock), American elm (*Ulmus Americana* L.), black cherry (*Prunus serotiona* Ehrh.), black ash (*Fraxinus nigra* Marshall), white spruce (*Picea glauca* (Moench) Voss), white pine (*Pinus strobus* L), northern white cedar (*Thuja occidentalis* L.), trembling aspen (*Populus tremuloides* Michx.) and balsam fir (*Abies balsamea* (L.) Mill) were also found in the overstory. The terrain within and surrounding the study site ranged from nearly level to glacial moraines and hilly till plains (Berndt 1988). The soil profile consists of ten soil types but were dominantly Champion cobbly silt loam with inclusions of Witbeck muck in the lower lying areas. The average temperature ranges from -9 °C in the winter and 18 °C in the summer. The mean annual precipitation is 84 cm (NOAA 2017).

3.2.2 Experimental design

This study is part of a long-term research project that investigated the effects of group-selection openings with a dominate or codominant yellow birch legacy-tree retained in each opening. (Shields et al. 2007, Shields et al. 2007, Shields et al. 2007, Klingsporn et al. 2012, Poznanovic 2013). The openings were created in the winter of 2003 (Shields et al. 2007). Three size groups were created, opening sizes were determined by a ratio of the of the surrounding forest canopy height (22m) to opening size. Ratios of 0.5 (n = 16), 1.0 (n = 17), and 1.5 (n = 16) were used resulting in canopy openings that were 267 ± 15 m^2, 642 ± 21 m^2, and l1192 ± 39 m^2 [mean ± SE], respectively. A dominant or co-dominant yellow birch was retained at the center of each opening, and each opening

perimeter was located at least 60 meters away from all other openings to reduce the likelihood that one opening would influence the environment and vegetation response in another (Fig 3.1).

Twenty reference sites that were centered on a dominant or codominant yellow birch were also identified in the surrounding forest. Reference sites were located in the adjacent management unit that had been managed by single-tree-selection on a cutting cycle of 10-15 years. The BDq method of harvest regulation was utilized, with a target basal area of 16.1 m^2/ha, a maximum diameter of 50.8 – 55.9 cm and a q-ratio of 1.3 with 5 cm size classes (Schwartz 2004).

3.2.3 Data collection

Regeneration plots were installed in each opening and in all reference sites the summer of 2005, and re-measured in the summer of 2012 in the same manner. Four plots were placed within one meter of the legacy-tree's trunk along the North, East, South, and West transects. Eight more plots were randomly placed in the harvested space of the opening along transects in the cardinal and subcardinal directions. Each regeneration plot consisted of a 3.14 m^2 circular plot. At each plot, tree saplings were counted and recorded by species.

In the summer of 2016 a subset of the original plots were surveyed. An additional four more regenerations plots were added to the study. The new plots were placed along each cardinal direction and located under the canopy of the surrounding forest (Fig 3.2). In 2016 sapling height was recorded for each sapling within the plot. For this study,

saplings were defined as any tree species 50 cm tall or greater up to 10 cm DBH. In order to accurately measure tall saplings, we used a telescoping measuring pole (Fig. 3.3).

We sampled 44 openings (small, n=13, medium, n = 15, large, n = 16) and 19 control sites for a total of 756 plots. Data was collected in the summer of 2016 between the months of June and August. In each opening a total of 12 regeneration plots were measured (three on each of the four cardinal transects). We measured a total of 528 regeneration plots in the opening and 228 regeneration plots at the reference sites.

3.2.4 Data analyses

To test our hypothesis that there would be differences in sapling height among the opening sizes and locations within the openings we calculated the mean tallest sapling height for each plot from the data collected in 2016. We then used analyses of variance (ANOVA) test to compare which variables were statistically significant at an alpha of 0.05. To test for the assumptions of normality and constant variance of errors normal probability plots and standardized residuals were used. Our dependent variables were tested one at a time and included tallest sapling height and tallest sugar maple sapling height from each plot. The independent variables included; opening size (reference, small, medium, large), plot position along the transect (under the legacy-tree, within the opening, and under the surrounding forest canopy), and transect direction (North, East, South, West). We also included all possible combinations of the independent variables to account for possible interactions. When the independent variables were found to be

statistically significant (alpha = 0.05), we used pairwise comparisons with the Holm's correction factor to determine which levels of the variable were significantly different.

To better interpret the results, we created a graphical representation of the mean tallest sampling height (±1 standard error) for each opening size and reference locations. This was done for both the tallest saplings in each plot as well as the tallest sugar maple sapling in each plot from the data collected in 2016.

3.3 Results

Of the 756 plots that were sampled, 542 contained at least one sapling. The sapling category was dominated by sugar maple with it comprising 77% of the tallest saplings across all plots. Red maple (12%) was the next most common species. Black cherry was 8% of the total and the remaining 7% were other species (ironwood, balsam fir, yellow birch, white pine, black ash, American elm, pin cherry, and eastern hemlock, in order of most to least abundant).

3.3.1 All species sapling height results

Sapling height differed significantly between plot locations (P = 0.01). The saplings in plots located under the legacy tree were significantly taller than saplings in plots that were in the opening (P = 0.012, Fig. 3.4). The tallest saplings were located in plots under the legacy tree (493.9 ± 22.6 cm, mean ± 1 SE) and the shortest saplings were in the plots that fell within the opening (401.1 ± 20.7 cm) (Fig. 3.4). Also, sapling height varied by opening size with the sapling located in the reference sites being significantly shorter than any opening sizes; small (P = 0.044), medium (P = 0.002) and large (P =

0.027) (Fig. 3.5). None of the interaction terms were found to be statistically significant (all P values > 0.05).

As seen in Fig 3.6-3.10 the highest amount of variation in the tallest sapling heights can be found in the reference sites and the lowest amount of variation is in the small openings. We also found high height variation in plots that were located under the forest canopy in the medium and large openings (Fig 3.10). While in the small openings, high variation was found along the west transect (Fig 3.7).

3.3.2 Sugar maple sapling height

The tallest sugar maple saplings were found in the small openings (559.6 ± 36.3 cm) while the shortest sugar maple saplings were found in the reference plots (366.4 ± 34.1 cm). Average tallest sugar maple sapling height in medium openings was 466.8 ± 29.0 cm and in large opening it was 441.5 ± 27.7 cm (Fig 3.11). There were statistically significant differences among opening sizes (P = < 0.000). Small openings had significantly taller sugar maple saplings than large openings (P = 0.055) as well as reference sites (P = 0.001). Plot transect azimuth and plot location were not significant factors in the ANOVA (P = 0.718 and P = 0.081, respectively).

Similar to the analysis of all species tallest sapling data, we found the reference sites to have the largest variation in height (Fig 3.12-3.16). We also found large variation in the plots located under the forest canopy in the medium and large openings. The highest variation in the tallest sapling height was found under the legacy-tree along the east

transect (Fig 3.16). We did not see a pattern of variation within the small opening according to plot location (azimuth or position).

3.4 Discussion

The primary objective of this study was to investigate differences in the regeneration and recruitment among opening sizes and locations within man-made openings with legacy-tree retention, with special attention to the dominant species (sugar maple). Our results indicate that both opening size and plot location within the opening relative to the legacy-tree are statistically significant indicators of tree sapling height and therefore gap capture but, this result was not consistent between sugar maple saplings and all species saplings.

When we included all the species in our analysis we expected to find taller saplings in the largest openings, but our results indicate that was not the case. The small, medium and large openings were not statistically different from each other, but all three sizes were statistically different from the reference sites. This result could be due to the unique condition created by maintaining a legacy-tree in each opening and therefore changing the characteristics of the opening. While other studies found that microclimate conditions change with opening size, such as higher soil temperature and more light in larger openings, this might not be as influential in our openings due to the presence of the legacy-tree moderating the environment (Canham et al. 1990, Gendreau-Berthiaume et al. 2009).

In our all species analysis the heights of the saplings were also found to be different between locations, either under the crown of the legacy-tree, in the gap, or under the

forest edge. The saplings that were rooted under the legacy-tree were taller than the saplings in the harvested openings. This again maybe due to the microclimate conditions, such as higher moisture and lower temperature and similar light conditions under the legacy-tree compared to plots found in the opening. We hypothesized that this could also be due to the disturbance caused by the harvesting equipment in the winter of 2003. Harvesting equipment has been found to compact soil and affect tree growth (Greacen et al. 1980). Equipment operators tend to avoid areas directly adjacent to residual trees to prevent damage to the roots and bole of the tree. The presence of the legacy-tree in the center of the gap could have created a buffer of undisturbed and un-compacted soil that resulted in taller saplings in these plots.

When the tallest sugar maple saplings were analyzed separately, we found a trend with the tallest sapling being located in the small openings and the shorter saplings in the large openings. This is different than the all species results, because in that analysis we did not find a statistically significant difference between opening sizes. This was unexpected as we hypothesized that there would be a larger growth response from shade-tolerant sugar maple in the larger gaps which would result in taller saplings. It has been found that shade-tolerant species such as sugar maple may respond to as little as a 1-2% light increase (Canham 1989). The ability of sugar maple to respond to such a slight increase in light may have caused sugar maple in all of the opening to respond in a similar manner to the increase in light. In the larger openings where more light was provided, there could have been competition from shade intolerant and mid-tolerant species. This could have increased competition and therefore been led to less height growth.

We did not find evidence in our study that plot transect azimuth was significantly related to sapling height. This result was unexpected because according to Gendreau-Berthiaume (2009) and Canham (1990) light levels would vary thought out the opening with some sections of the opening receiving more light. We expected to see taller saplings in parts of the opening that received the most light such as the northern half, but this was not the case in our study (Canham et al. 1990, Gendreau-Berthiaume et al. 2009). This is likely due to the presence of the legacy-tree which would change the pattern of light by casting a shadow along the northern, eastern and western portions of the opening throughout the day as the sun moves across the sky, making light levels different than other studies on forest openings.

In conclusion, when considering harvested openings with legacy-tree retention as a management tool it is important to consider the goals and outcomes that are desired. The ability to predict which individuals will likely capture the opening may help managers to better understand the response of forest regeneration at an earlier stage. While we did not find an opening size that had significantly taller saplings in our study, this result could be due to the amount of time that has passed since harvesting the openings, also the presence of a legacy-tree. This legacy-tree may have created environmental conditions that are different than would be found in a traditional open and should be considered a caveat to this study.

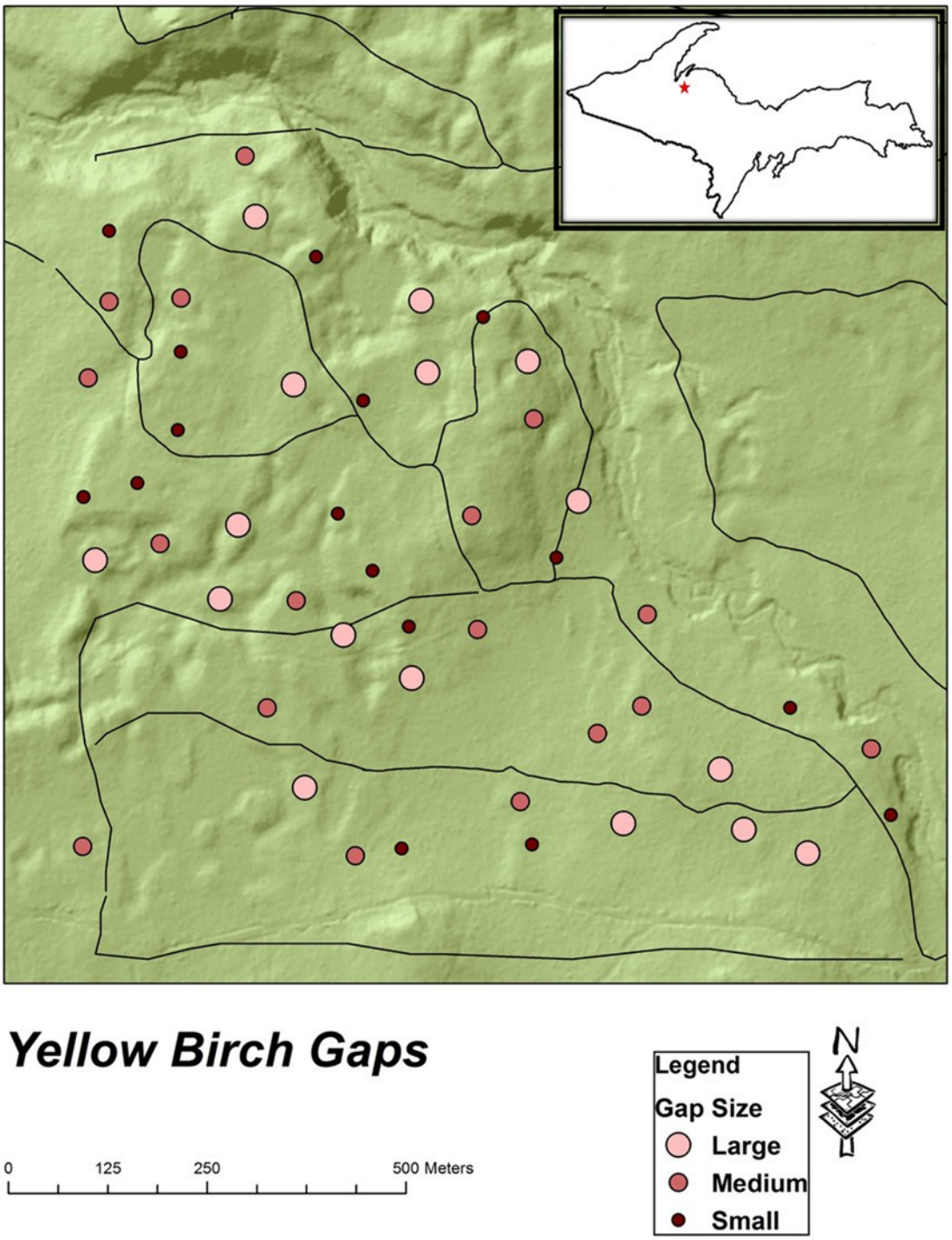

Figure 3. 1 Map of opening location within the Ford Center Research Forest. Black lines represent unimproved roads.

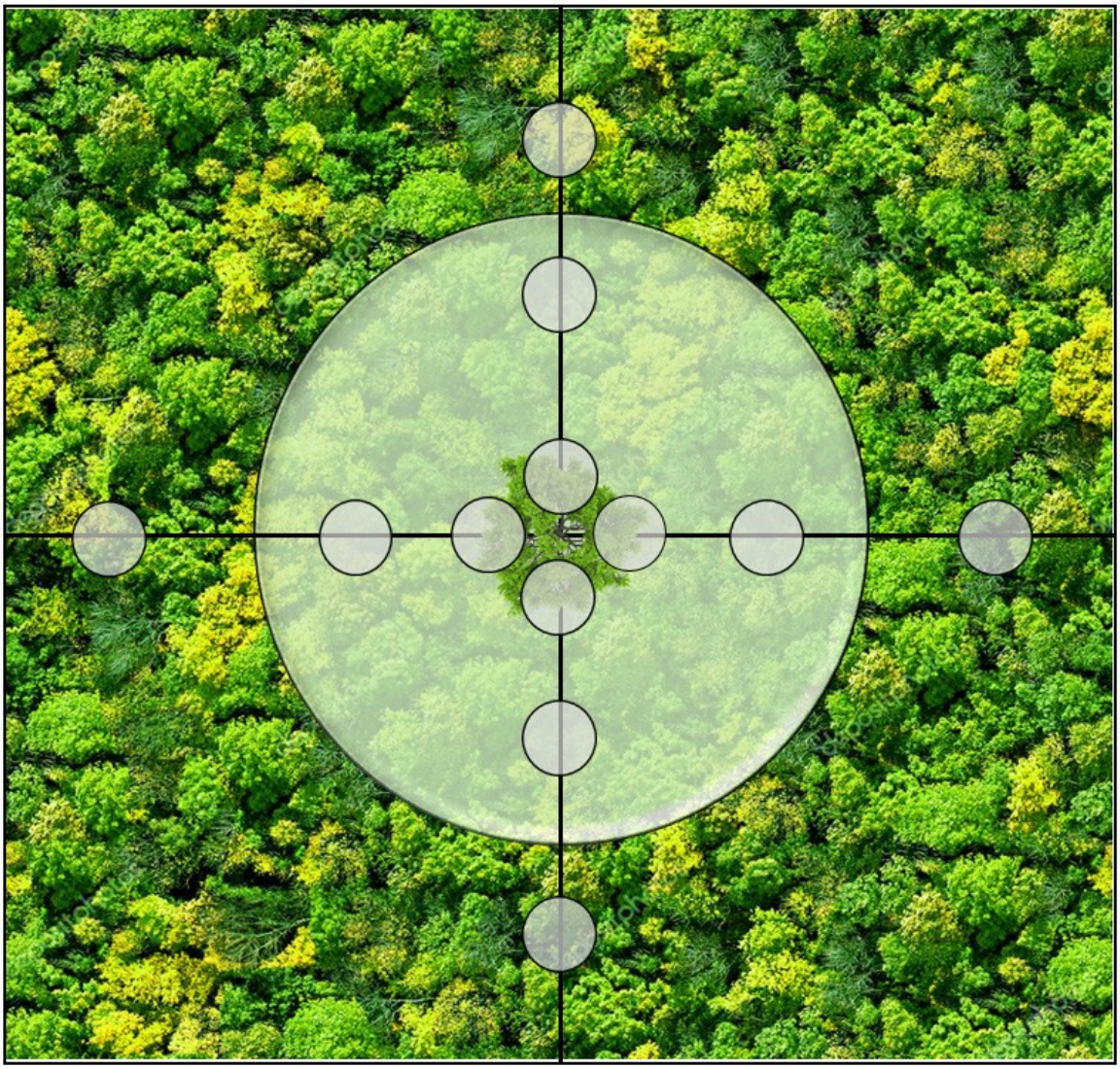

Figure 3. 2 Sampling design layout for data collection from the 2016 field season. Small circular plots are 3.14m^2 and randomly located around the legacy yellow birch in the opening center.

Figure 3. 3 Field technicians using the telescoping measuring pole to measure tall saplings in a yellow birch canopy gap at the Ford Center Forest in Alberta Michigan that was cut in the winter of 2003 (photo taken in 2016).

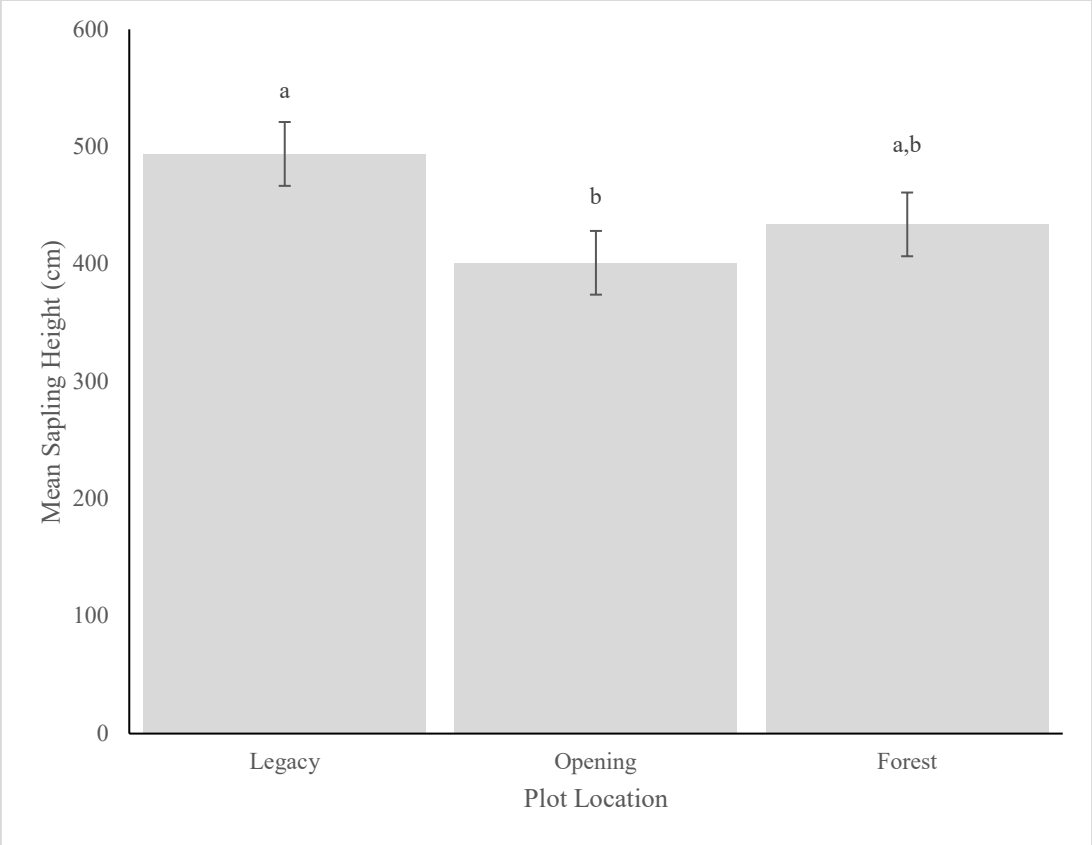

Figure 3. 4 Mean tallest sapling height by plot location. Letter indicate statistically significant differences ($P < 0.05$).

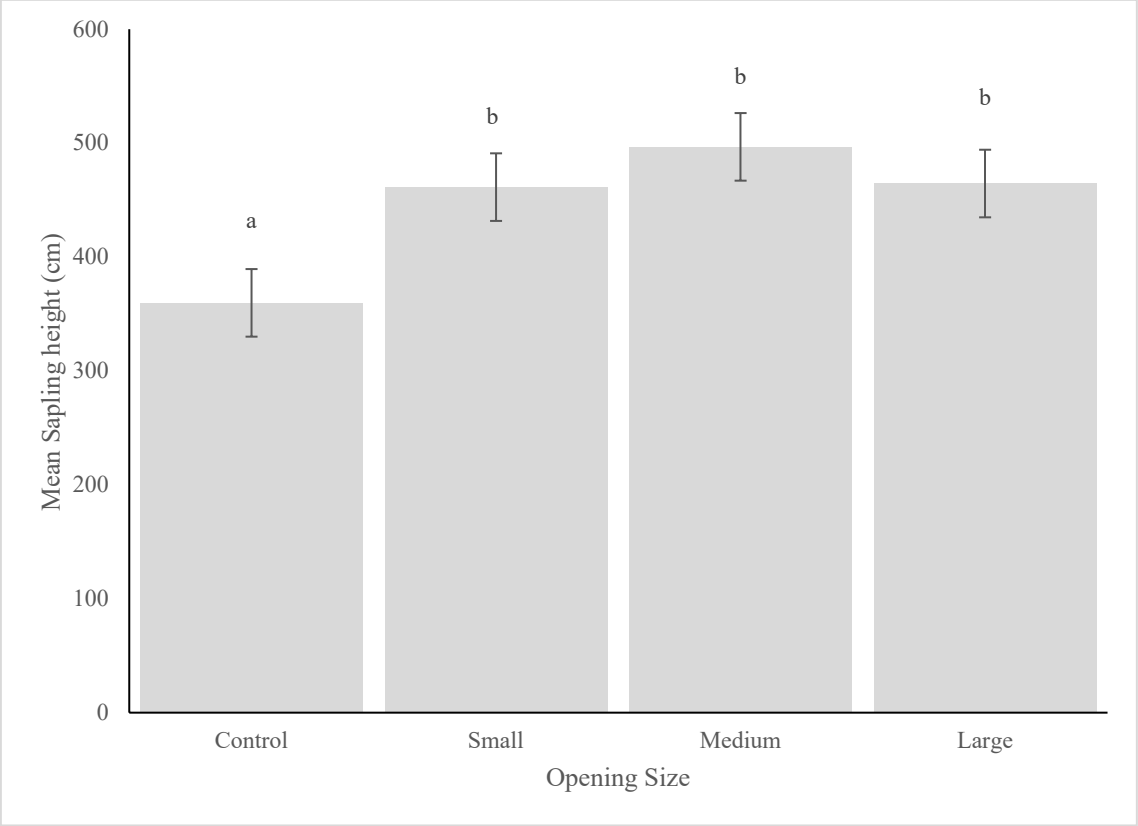

Figure 3. 5 Mean tallest sapling height by opening size. Letter indicate statistically significant differences ($P < 0.05$).

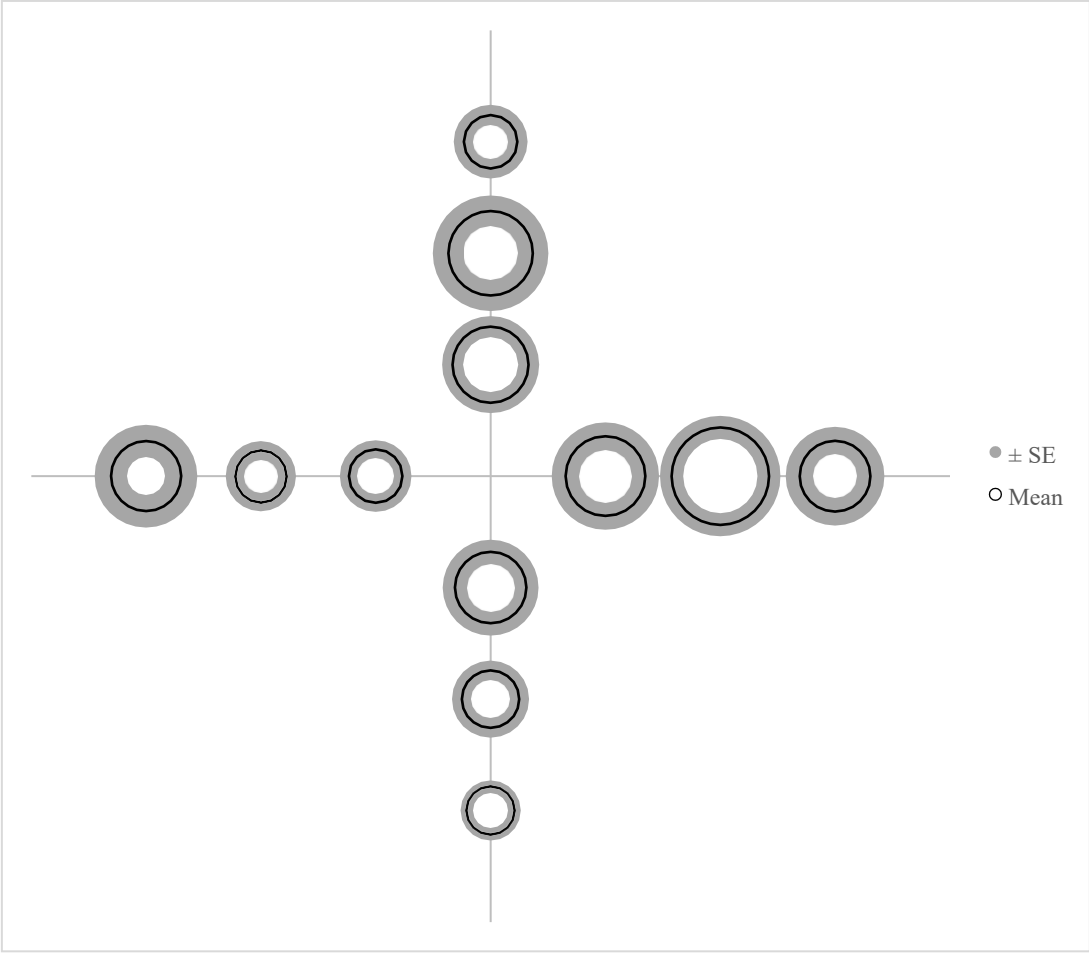

Figure 3. 6 Bubble graphical representation of the mean tallest sapling for reference locations. The black circle represents the average tallest sapling height of each plot location and the gray shading is ±1 standard error. The X, Y axis represent transect direction (north, east, south, west) with north being upward. The four central plots are under the crown of the legacy tree. The four middle plots are in the harvested opening and the four outside plots are under the forest canopy. Larger black circles indicated a larger mean tallest sapling height. Wider gray “doughnuts” indicate a larger standard error.

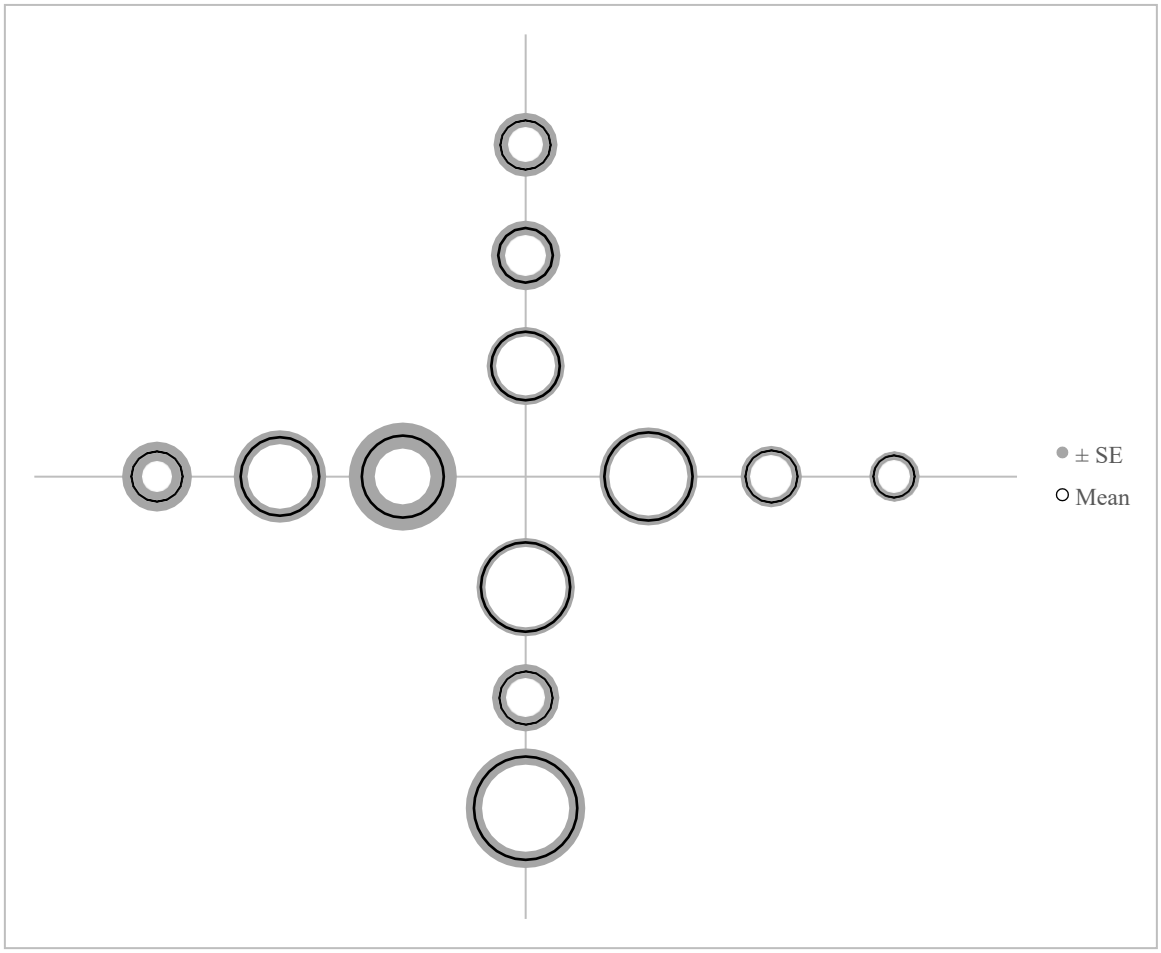

Figure 3. 7 Bubble graphical representation of the mean tallest sapling for small openings. The black circle represents the average tallest sapling height of each plot location and the gray shading is ±1 standard error. The X, Y axis represent transect direction (north, east, south, west) with north being upward. The four central plots are under the crown of the legacy tree. The four middle plots are in the harvested opening and the four outside plots are under the forest canopy. Larger black circles indicated a larger mean tallest sapling height. Wider gray "doughnuts" indicate a larger standard error.

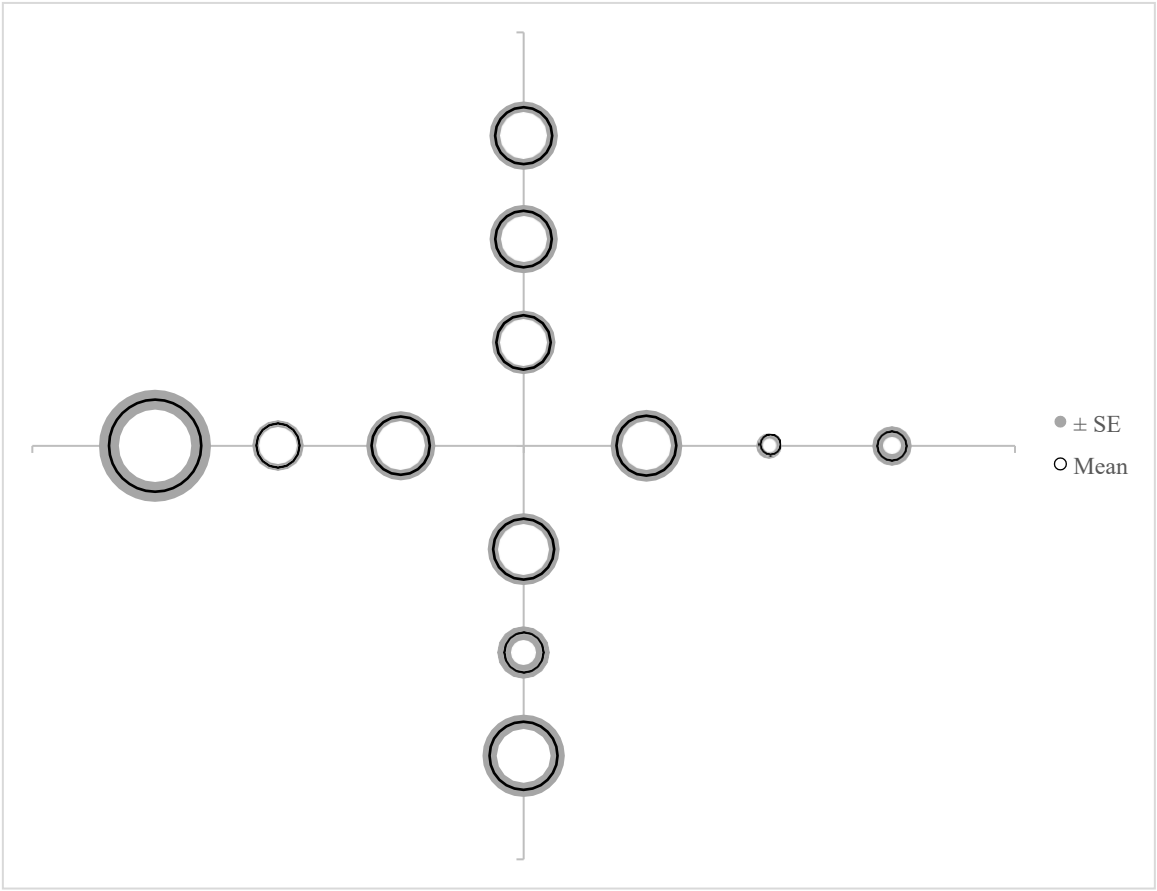

Figure 3. 8 Bubble graphical representation of the mean tallest sapling for medium openings. The black circle represents the average tallest sapling height of each plot location and the gray shading is ±1 standard error. The X, Y axis represent transect direction (north, east, south, west) with north being upward. The four central plots are under the crown of the legacy tree. The four middle plots are in the harvested opening and the four outside plots are under the forest canopy. Larger black circles indicated a larger mean tallest sapling height. Wider gray "doughnuts" indicate a larger standard error.

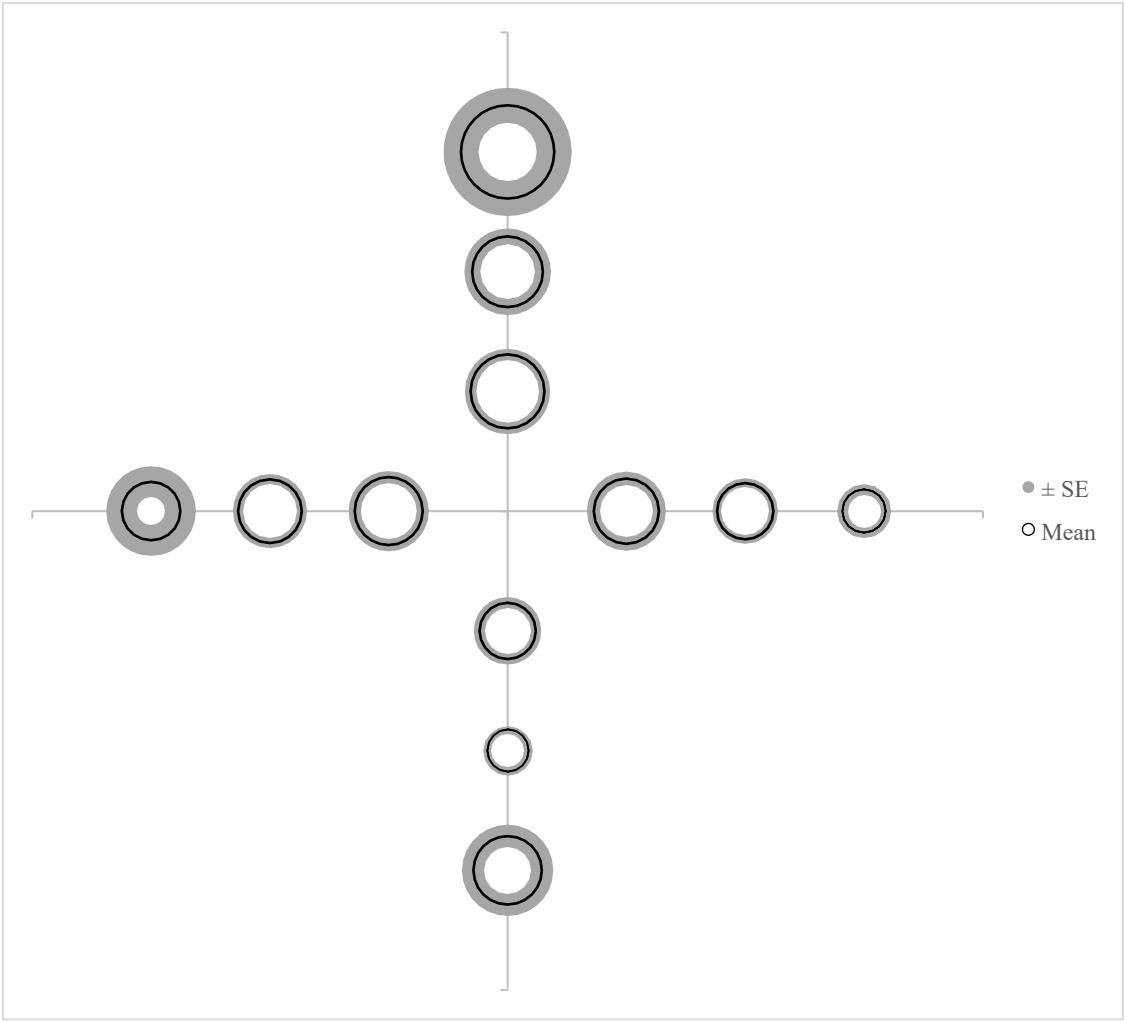

Figure 3. 9 Bubble graphical representation of the mean tallest sapling for large openings. The black circle represents the average tallest sapling height of each plot location and the gray shading is ±1 standard error. The X, Y axis represent transect direction (north, east, south, west) with north being upward. The four central plots are under the crown of the legacy tree. The four middle plots are in the harvested opening and the four outside plots are under the forest canopy. Larger black circles indicated a larger mean tallest sapling height. Wider gray "doughnuts" indicate a larger standard error.

Table 3. 1 Mean Height of the tallest sapling of all species by location.

Combined Species					
		Reference Sites		Medium Openings	
Direction	Location	Mean Height	1 Standard Error	Mean Height	1 Standard Error
North	Central Tree	416.4	114.7	481.2	80.9
North	Forest	292.6	111.1	503.5	101.4
North	Opening	461.9	170.7	499.3	103.4
East	Central Tree	293.3	99.0	515.2	95.4
East	Forest	383.6	178.8	814.7	175.2
East	Opening	279.8	104.6	381.9	61.1
South	Central Tree	391.0	133.6	538.7	96.8
South	Forest	259.6	70.1	601.4	126.0
South	Opening	314.1	108.0	338.6	122.8
West	Central Tree	436.3	151.4	529.3	105.0
West	Forest	387.3	152.9	245.5	100.3
West	Opening	533.1	126.4	167.3	52.5
		Small Openings		Large Openings	
Direction	Location	Mean Height	1 Standard Error	Mean Height	1 Standard Error
North	Central Tree	554.2	76.7	528.6	81.4
North	Forest	394.4	123.1	666.5	249.9
North	Opening	442.2	119.6	505.5	113.8
East	Central Tree	662.6	210.9	486.2	87.5
East	Forest	400.5	164.4	418.2	223.1
East	Opening	635.4	111.9	455.3	75.0
South	Central Tree	722.2	72.3	401.7	81.3
South	Forest	835.0	131.1	489.1	163.9
South	Opening	423.8	120.9	289.4	58.9
West	Central Tree	712.9	80.2	466.3	99.2
West	Forest	327.2	75.5	307.0	79.0
West	Opening	414.7	81.1	402.1	67.0

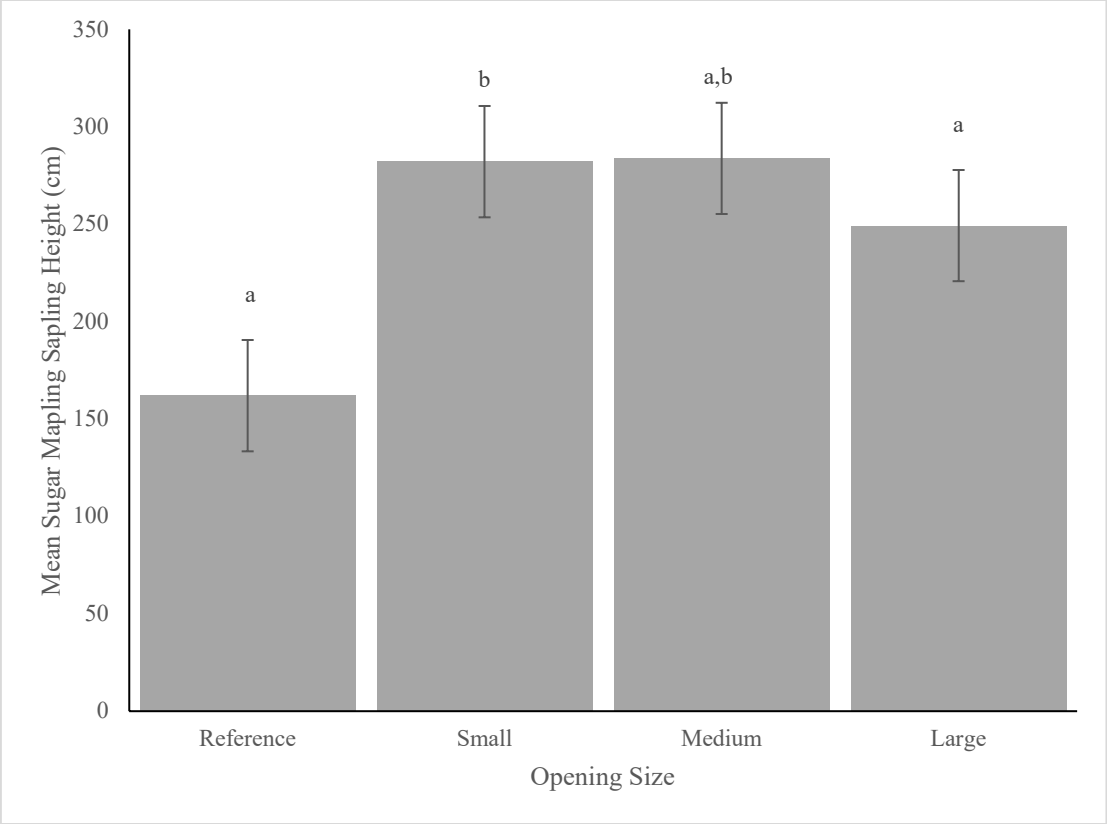

Figure 3. 10 Mean tallest sugar maple sapling height by opening size. Letter indicate statistically significant differences ($P < 0.05$).

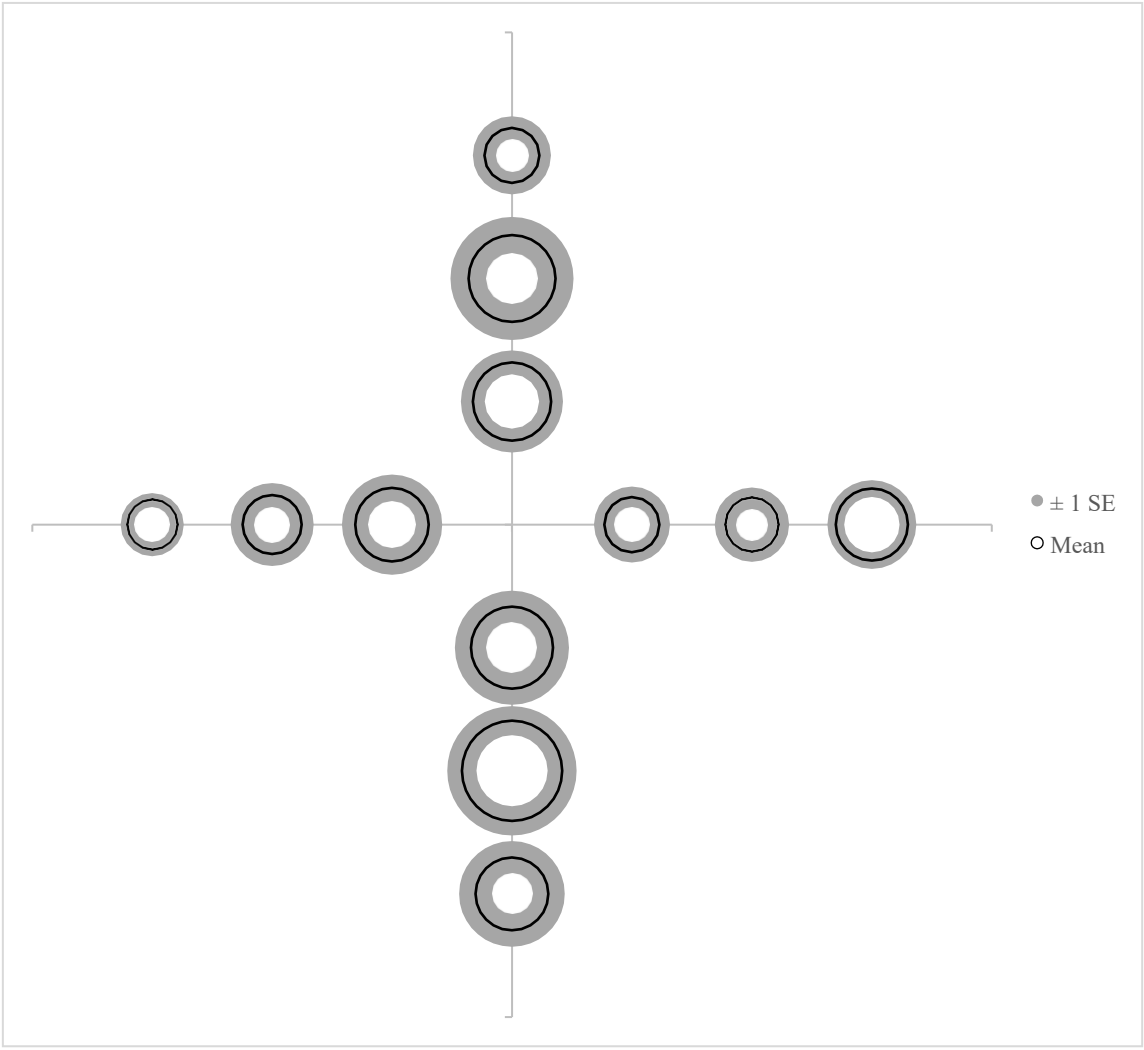

Figure 3. 11 Bubble graphical representation of the mean tallest sugar maple sapling for reference locations. The black circle represents the average tallest sapling height of each plot location and the gray shading is ±1 standard error. The X, Y axis represent transect direction (north, east, south, west) with north being upward. The four central plots are under the crown of the legacy tree. The four middle plots are in the harvested opening and the four outside plots are under the forest canopy. Larger black circles indicated a larger mean tallest sapling height. Wider gray "doughnuts" indicate a larger standard error.

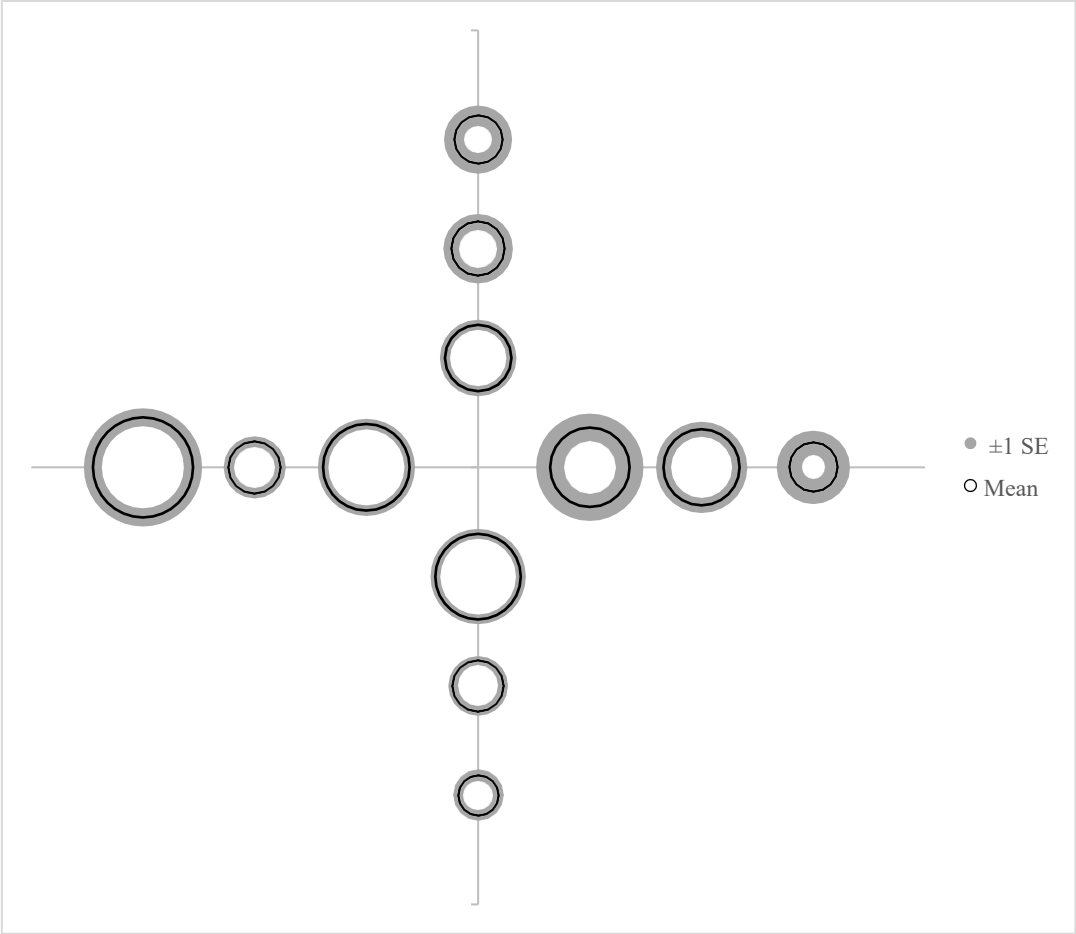

Figure 3. 12 Bubble graphical representation of the mean tallest sugar maple sapling for small opening. The black circle represents the average tallest sapling height of each plot location and the gray shading is ±1 standard error. The X, Y axis represent transect direction (north, east, south, west) with north being upward. The four central plots are under the crown of the legacy tree. The four middle plots are in the harvested opening and the four outside plots are under the forest canopy. Larger black circles indicated a larger mean tallest sapling height. Wider gray "doughnuts" indicate a larger standard error.

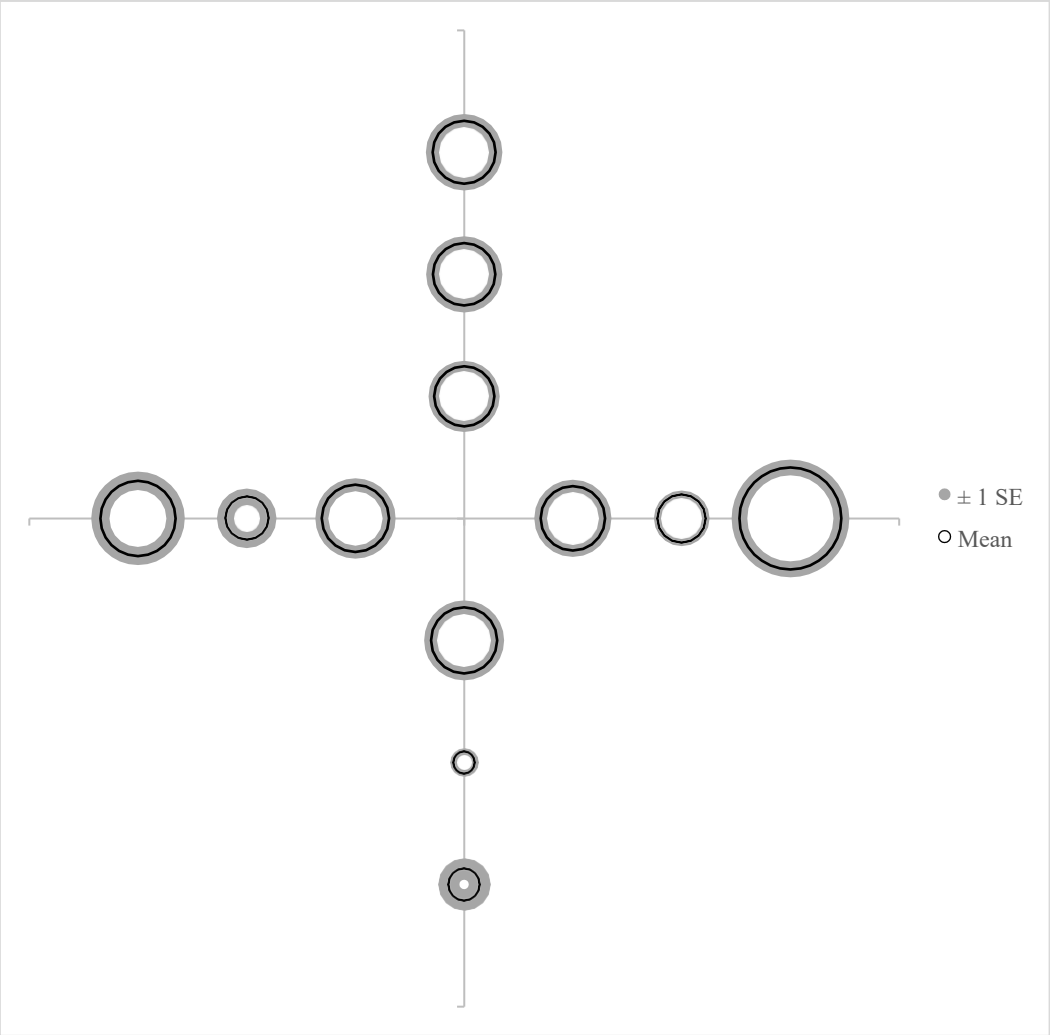

Figure 3. 13 Bubble graphical representation of the mean tallest sugar maple sapling for medium openings. The black circle represents the average tallest sapling height of each plot location and the gray shading is ±1 standard error. The X, Y axis represent transect direction (north, east, south, west) with north being upward. The four central plots are under the crown of the legacy tree. The four middle plots are in the harvested opening and the four outside plots are under the forest canopy. Larger black circles indicated a larger mean tallest sapling height. Wider gray "doughnuts" indicate a larger standard error.

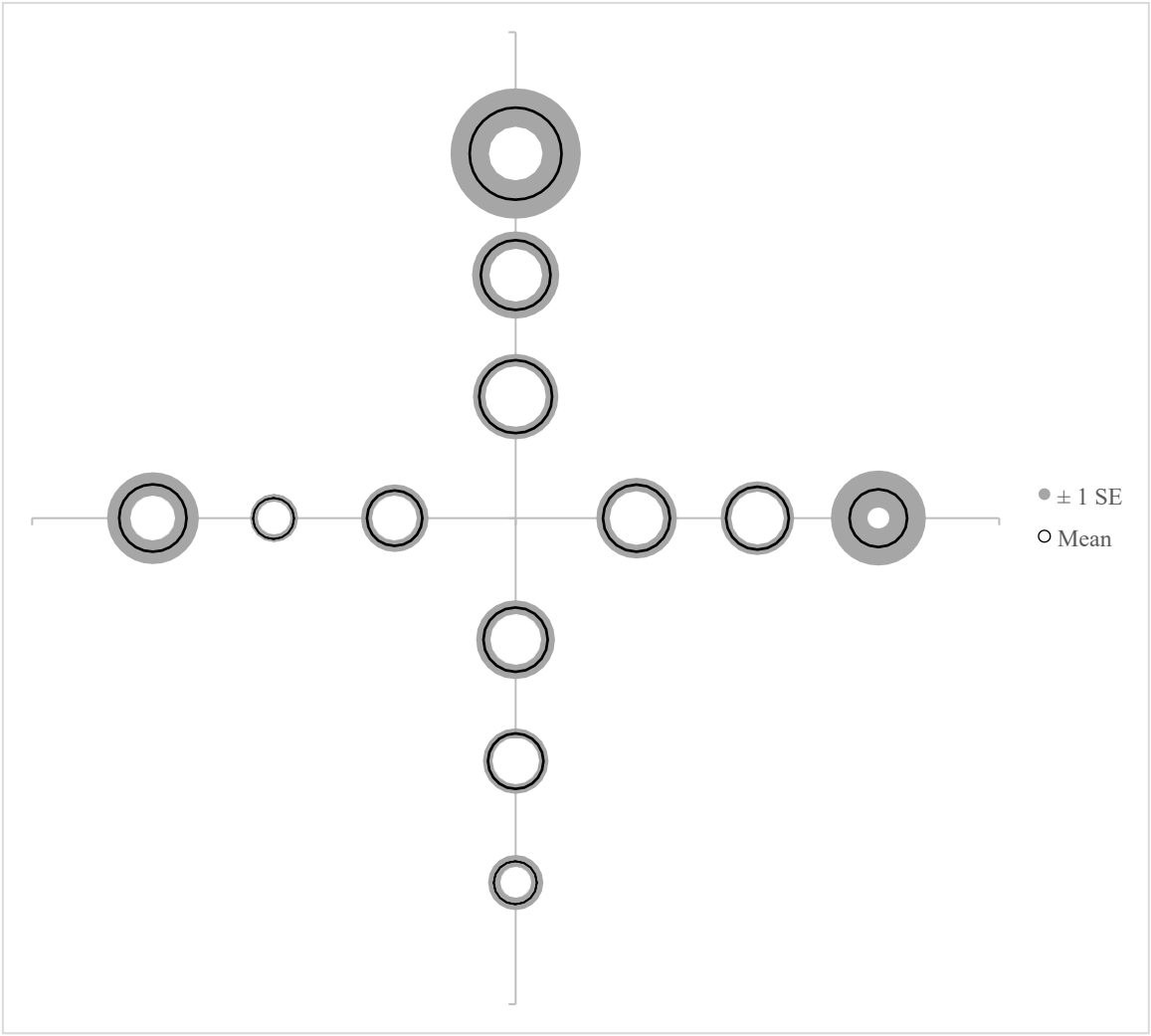

Figure 3. 14 Bubble graphical representation of the mean tallest sugar maple sapling for large openings. The black circle represents the average tallest sapling height of each plot location and the gray shading is ±1 standard error. The X, Y axis represent transect direction (north, east, south, west) with north being upward. The four central plots are under the crown of the legacy tree. The four middle plots are in the harvested opening and the four outside plots are under the forest canopy. Larger black circles indicated a larger mean tallest sapling height. Wider gray "doughnuts" indicate a larger standard error.

Table 3. 2 Mean Height of the tallest sugar maple sapling by location.

Sugar Maple					
		Reference Sites		Medium Openings	
Direction	Location	Mean Height	1 Standard Error	Mean Height	1 Standard Error
East	Central Tree	293.3	111.2	102.9	515.2
East	Forest	383.6	89.1	126.0	814.7
East	Opening	279.8	115.5	63.7	381.9
North	Central Tree	416.4	127.0	88.0	481.2
North	Forest	292.6	123.0	108.8	503.5
North	Opening	461.9	192.6	110.2	499.3
South	Central Tree	391.0	142.3	103.6	538.7
South	Forest	259.6	76.1	146.3	601.4
South	Opening	314.1	127.4	138.1	338.6
West	Central Tree	436.3	170.8	110.7	529.3
West	Forest	387.3	174.8	170.2	245.5
West	Opening	533.1	154.8	53.8	167.3
		Small Openings		Large Openings	
Direction	Location	Mean Height	1 Standard Error	Mean Height	1 Standard Error
East	Central Tree	662.6	233.2	486.2	97.7
East	Forest	400.5	211.3	418.2	270.7
East	Opening	635.4	125.8	455.3	78.7
North	Central Tree	554.2	84.5	528.6	90.6
North	Forest	394.4	173.9	666.5	277.8
North	Opening	442.2	138.0	505.5	127.1
South	Central Tree	722.2	88.0	401.7	88.2
South	Forest	835.0	150.7	489.1	175.4
South	Opening	423.8	94.8	289.4	59.2
West	Central Tree	712.9	81.5	466.3	105.7
West	Forest	327.2	91.6	307.0	93.4
West	Opening	414.7	83.6	402.1	73.3

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4 Conclusion Chapter

In conclusion, we analyzed the current conditions of harvested openings that contained a yellow birch (*Betula alleghaniensis* Britt.) legacy-tree at the center. The openings were divided into three size categories (small, medium and large) based on the perimeter of the opening as measured in the winter of 2004 and a reference category that were plots established in the surrounding forest and also centered on a yellow birch. Understanding how these openings influence the distribution of herbaceous plants and cover groups was one of the goals of this projects. We also tested to see where the tallest saplings were growing within the openings as well as in the reference sites. Having a better understanding of these factors can help forest managers if they are considering openings with tree retention as a possible management tool.

The main objective of this study was to measure how openings influence the herbaceous layer, cover groups and sapling heights. To test our hypothesis, we used the environmental variables of opening size, plot transect azimuth and plot location. We used these measures to see how the dependent variable changed with opening size, in the space of the opening and into the surrounding forest. This is important because if openings with a legacy-tree retained in the center are going to be used as a possible management option we need to understand how the understory community may respond.

One of the more interesting observations that we made was that while we expected opening size to be the most important predictor variables in our analysis this was not always the case. Our results indicate that opening size is a predictor for certain variables such as seedling percent cover and shrub percent cover, but not for all the variables that

were measured. Opening size was not the only variable that we found to be statistically significant. As we observed with herbaceous species percent cover, plot location within the opening was also a significant variable. This is important because when deciding if openings are an appropriate tool, the management goals and objectives must be clear.

A unique piece of this research project was that there was a yellow birch left in the middle of each opening. Because of this our work is different than many other research projects that focus on manmade openings (Coates et al. 1997, Gendreau-Berthiaume et al. 2009, Kern et al. 2013). It is important to consider our results in the context our experimental design. Plots located under the legacy-tree were different than other locations when considering Shannon's diversity index, species richness, shrub percent cover and herbaceous community percent cover. If a legacy-tree is to be left as a possibly seed source within an opening, the impact of the retention must be well understood.

During our analysis, we include a variable for plot transect azimuth (North, South, East and West) in each of the ANOVA tests. We hypothesized that azimuth would have an influence on herbaceous species percent cover, cover groups as well as sapling height because of the direction of light entering the opening. We were not able to find any evidence that azimuth influenced any of the variables. It is likely that the legacy-tree was one probable reason for the lack of evidence. The legacy tree would have changed the amount of light and possibly other resources, such as soil moisture and temperature that would have been found in a traditional harvested opening. This could have caused the

legacy-tree to have a modifying effect on the surrounding opening and make azimuth a less important variable.

This study was done as part of a long-term research project associated with the Michigan Technological University Ford research forest that has been studying these openings since their creation in 2003 (Shields et al. 2007, Shields et al. 2007, Shields et al. 2007, Poznanovic 2013, Poznanovic et al. 2013). It is a piece in the ongoing research at this site on opening dynamics with legacy-tree retention. Long term research projects such as this are an important part of understanding forest dynamics. Without these types of experiments, it is difficult to understand the emerging patterns of forests post-harvest. To have a more concise understanding of what happens in a northern hardwood forest when openings are created with legacy-tree retention it is important to have ongoing research.

Further research is needed to see what role other environmental factors play in this novel silvicultural approach. To further our understanding of understory diversity in these openings I suggest taking specific microclimate measurement such as soil moisture, soil temperature and available light at each of the study plots. I believe that this additional information will help us better understand the outcomes of studies like this one. I would also suggest permanent tags on the tallest saplings found in each opening. With permanent tags, we would be able to monitor the tallest sapling to see if our predictions of gap capture are accurate. Also, we will be able to measure if the sapling that is tallest now continues to dominate through time or if it is over topped by a different sapling as the stand goes through the stages of succession. Being able to monitor specific sapling

into the future would provide valuable insight about gap capture and future forest composition.

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Appendix A. Species List, Common Name and Species Codes.

A.1 List of All Species Recorded with Species Codes

Species	Common Name	Species Code
Herbs/Forbs/Shrubs		
Actaea rubra	Bain berry	act rub
Anemone nemorosa	wood anemone	ane qui
Anemone quinquefolia	bitter dock	rum obt
Aralia nudicaulis	wild sarsaparilla	ara nud
Arisaema triphyllum	jack in the pulpit	ari tri
Athyrium filix-femina	lady fern	ath fil
Caltha palustris	marsh marigold	cal pal
Chrysanthemum leucanthemum	oxeye daisy	chr leu
Circaea alpina	small enchanter's nightshade	cir alp
Clintonia borealis	blue bead lily	cli bor
Coptis trifolia	golden thread	cop tri
Cornus canadensis	bunchberry	cor can
Cypripedium acaule	pink lady slipper	cyp ace
Deparia acrostichoides	silver spleenwort	ath the
Dryopteris carthusiana	spinulos shield fern	dry car
Equisetum sylvaticum	woodland horsetail	equ syl
Fragaria virginiana	wild strawberry	fru vir
Galeopsis tetrahit	hemp nettle	gal tet
Goodyera pubescens	rattlesnake plantain	goo obl
Gymnocarpium dryopteris	oak fern	gym dry
Hieracium aurantiacum	orange hawkweed	hei aur
Hieracium caespitosum	yellow hawkweed	hie cae
Huperzia lucidula	shining club moss	hup luc
Impatiens capensis	jewel weed	imp cap

Lactuca canadensis	wild lettuce	lac can
Lonicera canadensis	fly honeysuckle	lon can
Lonicera canadensis	bush honeysuckle	die lon
Lycopodium annotinum	interrupted clubmoss	lyc inn
Lycopodium obscurum	ground pine	lyc fon
Maianthemum canadense	Canadian mayflower	mai can
Maianthemum racemosum	false Solomon seal	mai rac
Matteuccia struthiopteris	ostrich fern	mat str
Mitchella repens	partridgeberry	mit rep
Monotropa uniflora	Indian pipe	mon uni
Oenothera biennis	evening primrose	epi spp
Onoclea sensibilis	sensitive fern	ono sen
Osmunda cinnamomea	cinnamon fern	osm cin
Osmunda claytoniana	interrupted fern	osm cla
Oxalis acetosella	wood sorrel	oxa ace
Persicaria sagittata	arrow leaf tearthumb	per sag
Phegopteris connectilis	beech fern	phe con
Polygonatum pubescens	true Solomon’s seal	pol pub
Prenanthes spp	rattlesnake root	pre spp
Pteridium aquilinum	bracken fern	pte aqu
Ranunculus acris	tall buttercup	ran acr
Ranunculus repens	creeping buttercup	ran rep
Ribes glandulosum	skunk currant	rib gla
Ribes triste	wild red currant	rib str
rubus allegheniensis	blackberry	rub all
Sambucus canadensis	common elderberry	jam can
Sambucus racemosa	red elderberry	sam rac
Scutellaria lateriflora	blue scull-cap	scu let
Solidago spp	golden rod species	sol spp
streptopus roseus	rosy twisted stalk	str ros

Taraxacum	dandelion	tar off
Trientalis borealis	star flower	tri bor
Trillium cernuum	nodding trillium	tri cer
Trillium grandiflorum	large trillium	tri gra
Uvularia grandiflora	bellwort	uvu gra
Veronica officinalis	common speedwell	ver off
Viola spp	wild violet	vio spp
Trees		
Abies balsamea (L.) P. Mill.	Balsam fir	abi bal
Acer rubrum L.	Red maple	ace rub
Acer saccharum Marsh.	Sugar maple	ace sac
Amelanchier spp. Medik.	Serviceberry	ame spp
Betula alleghaniensis Britt.	Yellow birch	bet all
Fraxinus pennsylvanica Marshall	Green Ash	fra pen
Fraxinus nigra Marsh.	Black ash	fra nig
Ostrya virginiana (P. Mill.) K. Koch	Ironwood	ost vir
Picea glauca (Moench) Voss	White spruce	pic gla
Populus tremuloides Michx.	Trembling aspen	pop tre
Prunus serotina Ehrh.	Black cherry	pru ser
Tilia americana L.	American basswood	til ame
Thuja occidentalis L.	Northern white cedar	thu occ
Tsuga canadensis (L.) Carr.	Eastern hemlock	tsu can
Ulmus americana L.	American elm	ulm ame